Data Collection Survey
on
the Outer Ring Road Diversion Channel
in
the Comprehensive Flood Management Plan
for
the Chao Phraya River Basin
in
the Kingdom of Thailand

Final Report

(Summary)

June 2018

Japan International Cooperation Agency

Pacific Consultants Co. Ltd.
Oriental Consultants Global Co. Ltd.

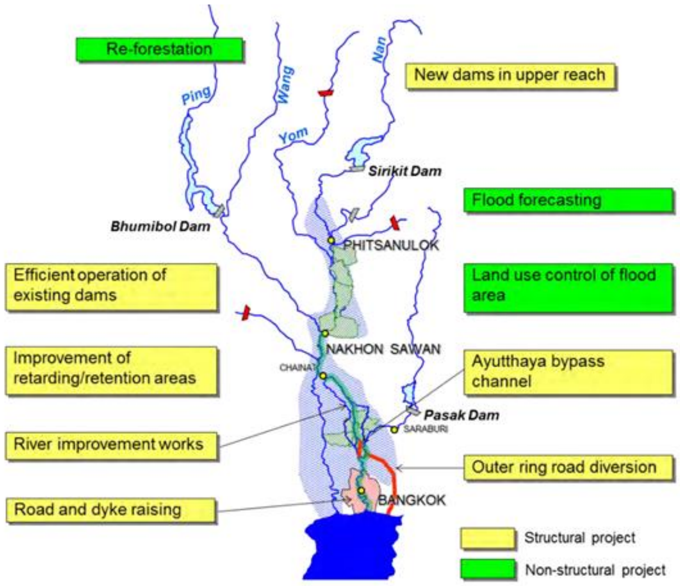
Summary

1: BACKGROUND AND OBJECTIVE

1.1 Background

The Chao Phraya River Basin (hereinafter called “the Basin”), which occupies about one-third of the total territory of the Kingdom of Thailand, have provided benefits for the agriculture through frequent floods. However, due to of rapid economic growth, the land use has drastically changed as more properties and assets concentrate in potential flood areas. Mitigation of floods risks has become an urgent issue due to the urban development. During the severe flood in 2011, seven industrial estates in the north of Bangkok were inundated, and 469 Japanese companies were affected by this severe flood. The economic loss was estimated at approximately THB 1,400 billion.

JICA prepared and submitted the Comprehensive Flood Management Plan for the Chao Phraya River Basin (hereinafter called “the Master Plan (JICA MP)”) upon the request from the Royal Thai Government in June 2013. In JICA MP, the city of Bangkok and the surrounding areas (to the east of Tha Chin River, and to the south of Pasak River in the city of Ayutthaya), which the Royal Thai Government designated as the priority Protected Area, were defined as the priority area for protection, for which the following structural and nonstructural measures were proposed.



Source : JICA Study Team

Figure 1: Projects Proposed in the JICA MP

The Royal Irrigation Department (RID) had been planning for the implementation of the 3rd Outer Ring Road Diversion Channel with the integrated project of the Diversion Channel (hereinafter called “the Channel”) proposed in the JICA MP and the 3rd Outer Ring Road (East Section) (hereinafter called “the Outer Ring Road”) in cooperation with the Department of Highways (DOH) under the Ministry of Transport (MOT). In August 2016, the Royal Thai Government requested JICA’s support in conducting a Feasibility Study to analyze the feasibility of the concept of RID’s integrated project plan.

Through the discussion with RID, JICA determined that basic studies before the F/S such as the formulation of the basic plan prior to the implementation of the integrated project of the 3rd Outer Ring Road (East Section) and the Diversion Channel was important, and also the mutual understanding and agreement between RID and DOH was the key issue for the integrated project of the Third Outer Ring Road (East) and the Diversion Channel.

This study was conducted in this context.

1.2 Objectives

The following are objectives of this study.

- Study the basic plan for the Outer Ring Road Diversion Channel at the Pre F/S stage.
- Preparation of the proposal to identify the necessary items in the additional study required for RID to implement the project and points of concern for the construction of the Diversion Channel after the formulation of the basic plan.

2: CONCLUSION

In this study, we clarified the following on the Outer Ring Road Diversion Channel proposed by JICA MP.

- Effectiveness and efficiency of the Outer Ring Road Diversion Channel from the viewpoint of flood control against the flood with the same scale as the flood in 2011.
- Advantages in the implementation of the integrated project with the 3rd Outer Ring Road (East), optimal alignment and construction schedule.
- By proceeding with the proper project priority, Protected Area including seven industrial parks can be protected against the flood with the same scale as the flood in 2011.
- From the viewpoint of project implementation study, all difficulties in the construction can be resolved.
- From the viewpoint of economic evaluation, the project is economically and financially feasible.

3: SUMMARY OF THE STUDY

The schedule and general activities of the Study were explained in Chapter 1: Outline of the Study.

The duration of this study was 18 months, from January 2017 to June 2018.

In this study, 3 high level seminars were held jointly by JICA, RID and DOH. The seminars' objective was to clarify the advantages and feasibility of the integrated project of the Third Outer Ring Road (East) and the Diversion Channel.

In May 2017, the main counterpart members were invited to see Japanese knowledge and technology in the implementation of the integrated project of the roads and the diversion channels.

In Thailand, several discussions with RID and DOH were made in order to elaborate materials for National Water Resources Committee, to consider the advantages of RID projects.

As part of public relations activities, communication materials were prepared every time and reports were submitted in order to explain the Diversion Channel's effectivity and the contents of JICA MP were elaborated in Japanese, English and Thai.

The effectiveness and the necessity of the Outer Ring Road Diversion Channel were explained in Chapter 2: Basic Plan. It includes basic information and basic design of the main structures.

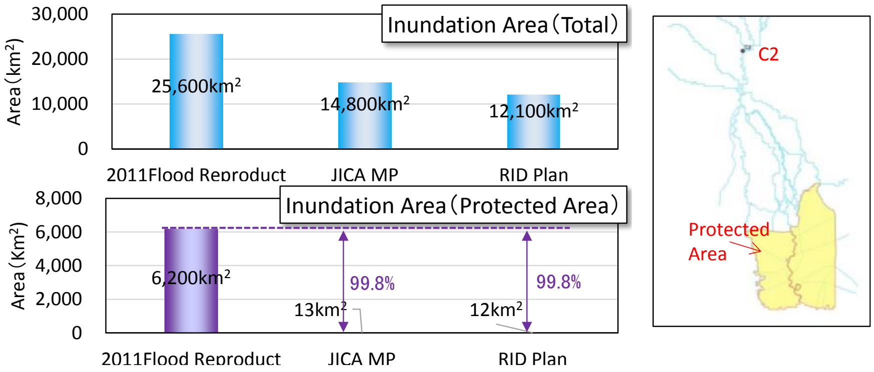
Table 1：Conditions of Comparison of the Effectiviness between JICA MP and RID Plan (m^3/s)

	Ayutthaya Bypass	Outer Ring Road Diversion Channel	Chainat-Pasak Channel	Raphiphat Channel	Eastern Diversion Channel
JICA MP	1,200	500	210（current）	210（current）	(none)
RID Plan	1,200	500	800	400	800

Source：JICA Study Team

Figure 2 shows the results of the comparison of the reduction of the flood area with the target flood in 2011.

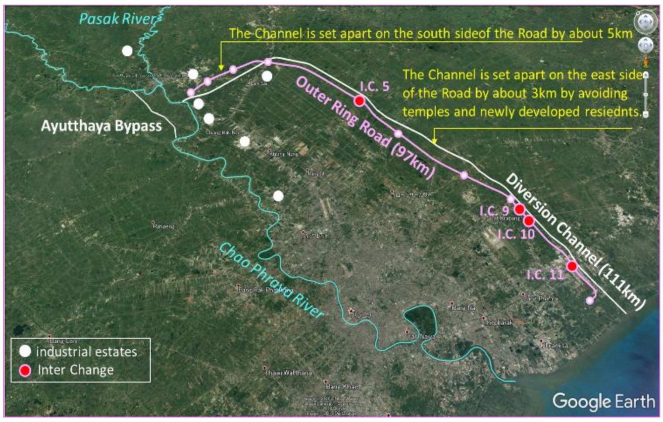
JICA MP proposed the measures to reduce approximately the same flood area in Protcted Area with concentration of assets and in all the basin as proposed in RID Plan with less investment than RID Plan. Therefore, JICA MP was considered to be an effective and efficient plan.



Source：JICA Study Team

Figure 2：Confirmation of the Reduction in Flood Damage by JICA MP

The basic route for the Diversion Channel was designed, it would be developed with the 3rd Outer Ring Road (East Section) together as an integrated project. The linear shapes were studied with 4 indicators used in project evaluation in Thailand (engineering, social impact, environmental impact and cost & benefit). As a result, the proposal with the lowest number of relocations required for families and factories was chosen.

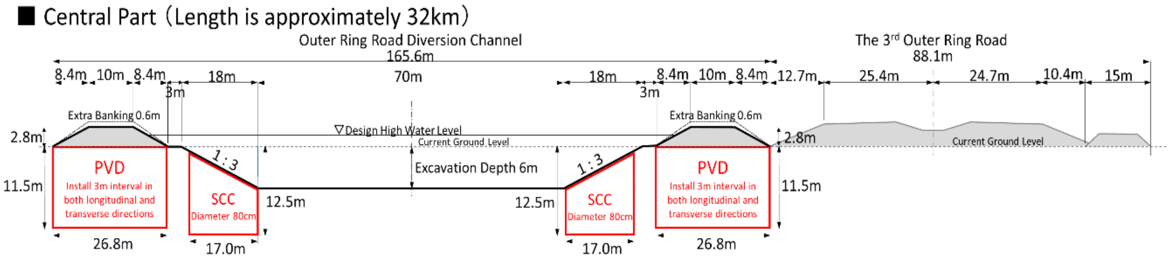


Source：JICA Study Team

Figure 3：Linear Shape of the Outer Ring Road Diversion Channel（Recommended）

Figure 4 shows the standard cross section for the implementation of the integrated project of the Diversion Channel and the Outer Ring Road. The maximum capacity of the Diversion Channel is 500 m^3/second. The capacity was confirmed the by the unsteady flow analysis.

Boring investigation and soil test were conducted in places where the Diversion Channel is planned to study the stability of the cross section of the Diversion Channel. As a result, in southern and middle sections with poor ground conditions, measures to stabilize the slope (Soil Cement Column method: SCC) and measures to promote drainage in soft clay ground (Prefabricated Vertical Drain method: PVD) are required.



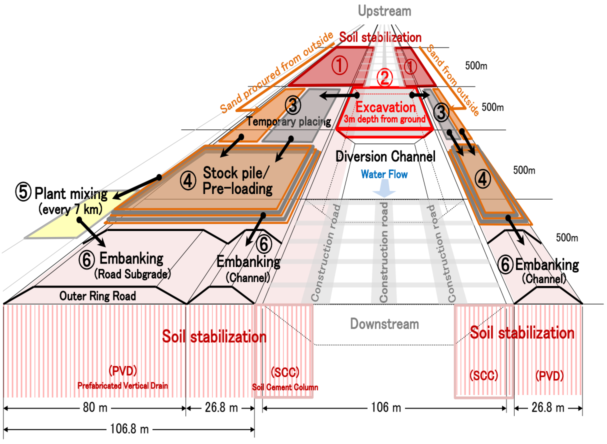
Source：JICA Study Team

Figure 4：Standard Cross Section of the Diversion Channel and the Outer Ring Road (middle section)

In Chapter 3: Implementation plan, procurement plan, construction plan, maintenance and administration plan and socio-environmental concerns are presented, along with the economic evaluation and the schedule of the project. It was demonstrated that challenge related to the construction of the Diversion Channel can be overcome, the construction can be completed within the stipulated period, and the plan is economically feasible.

In this study, the possibility of using the excavated soils (Soft clay called “Bangkok Clay”) as the material for the embankment of channel and road was studied. Results of the soil test was used to determine whether the soils meet the quality standard to be used as material for the embankment. As a result, it was determined that 10,700,000 m^3 can be used as material for the channel embankments, and 9,900,000m^3 can be used for the road embankments, out of 60,000,000m^3 of soils produced by the excavating for the Diversion Channel construction. This shows that the integrated project would be beneficial.

A concrete construction plan was presented. The Diversion Channel with a length of approximately 110 km is planned to be divided in 55 sections, each with a length of 2 km, to carry out the construction simultaneously. Therefore, an effective construction procedure in which the 2 km section will be futher divided into 500m units. This procedure will reduce the construction cost by using the excavated soil as material for the embankment of channel and road.



Source：JICA Study Team

Figure 5：Construction Plan for the Diversion Channel

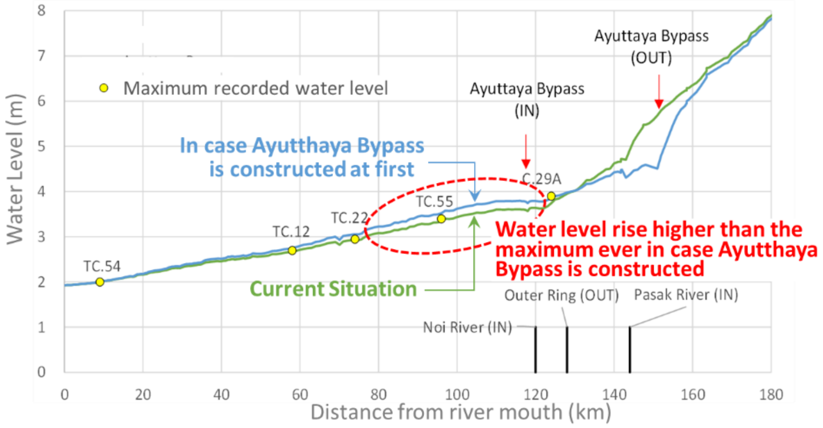
The construction of the Diversion Channel will be carried out simultaneously with the road construction in an integrated manner. Therefore, the construction plan was created, respecting DOH’s plan and taking into account that both the road and the Diversion Channel should be completed by the end of 2025.

Contents of 9 projects proposed by RID and JICA's opinion on them are presented in Chapter 4: RID's Plans and JICA's Opinion.

From October 2018, RID has been considering to put the priority on the Ayutthaya Bypass and the Eastern Diversion Channel (Widening Chainat-Pasak Channel and Construction of Pasak-Gulf of Thailand Channel) over the Outer Ring Road Diversion Channel.

JICA has pointed out that JICA Team is prioritizing the Protected Area that includes Bangkok and the industrial areas around Ayutthaya, while RID is attempting to proceed with the project with different criteria. The JICA Study Team has repeatedly pointed out that the following are especially important:

- Prioritizing the Ayutthaya Bypass would increase the flood risk in areas in the downstream and Bangkok where assets and industry are concentrated. This is not a appropiriate judgement. This judgement should be intensively examined for the optimum flood control. Refer to Fig.6
- Prioritizing the widening of Chainat-Pasak Channel located in the upstream would increase the flood risk in the urban and industrial areas in the eastern part of downstream Chao Phraya River.
- The correct procedure is the following:
    1. Implement an efficient operation of the existing dams and dyke raising in the lower Chao Phraya River as JICA MP proposed.
    2. Construct the Outer Ring Road Diversion Channel first, and then construct the Ayutthaya Bypass.
- By comparing the Outer Ring Road Diversion Channel proposed by JICA (A) and Eastern Diversion Channel (Widening Chainat-Pasak Channel and Construction of Pasak Gulf Channel) proposed by RID (B), it was determined the Outer Ring Road Diversion Channel would be more beneficial in terms of economic efficiency and the early completion of the construction. Refer to Fig.7.

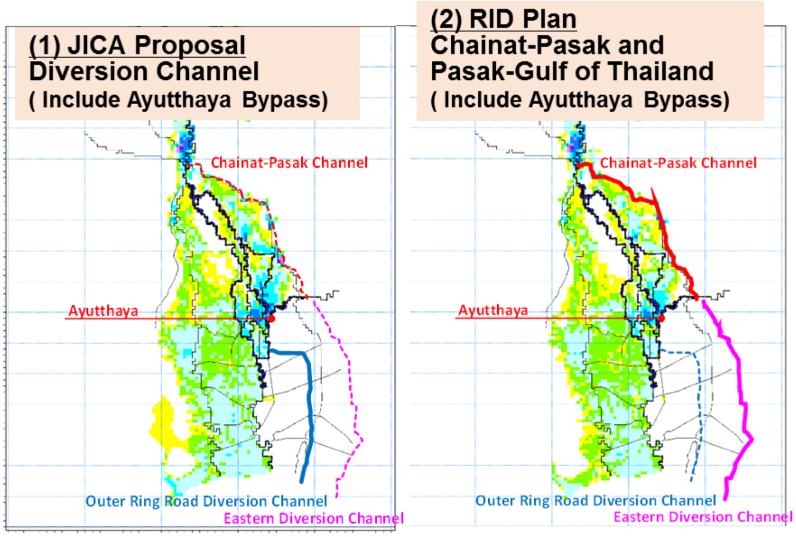


Source : JICA Study Team

Figure 6： Comparison of the Maximum Water Level with/without Ayutthaya Bypass in 2011 Flood

A) Outer Ring Road Diversion Channel Benefit/Cost (B/C) : 2.04, EIRR: 19.5%

B) Eastern Diversion Channel Benefit/Cost (B/C) : 1.49, EIRR: 13.9%



(1) JICA Proposal
Diversion Channel
(Include Ayutthaya Bypass)

(2) RID Plan
Chainat-Pasak and
Pasak-Gulf of Thailand
(Include Ayutthaya Bypass)

Item	A)	B)
Total length （km）	111	270
Construction Cost （Bil THB） ※ Include Ayutthaya Bypass Construction Cost	165.7	293.5
Project Period （Year）	5	15

Source : JICA Study Team

Figure 7 : Comparison between Outer Ring Road Diversion Channel (A) and Eastern Diversion Channel （B）

A proposal that includes necessary items for the RID to implement the project is presented from the following point of view in Chapter 5: Remaining Issues and Proposal.

1. A proposal of necessary items and points of concern in the additional study.
   1) Carry out geological survey around the Diversion Channel for the detailed design. The results may prompt the changes in the design that may affect the construction cost.
   2) Study the compensational method for the existing mangrove around the river mouth.
2. Point out the concern for the detailed design and the construction of the Outer Ring Road Diversion Channel

   It is ideal to carry out ground behavior simulation with FEM analysis (Finite Element Method Analysis) and the dynamic observation in the test construction in stages of the detailed design of the Diversion Channel and the Construction Plan.
3. Study the concrete measures to reduce DOH's costs

   In this study, lowering of the road height in the sections of the Outer Ring Road protected by the Diversion Channel was proposed in order to reduce construction costs. Concrete measures must be studied for the integrated project.

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Abbreviation

Abbreviation	English
AB	Ayutthaya Bypass
CP	Chainat Pasak
C/P	Counterpart
CBR	California Bearing Ratio
CPB	Crown Property Bureau
DC	Diversion Channel
DDPM	Department of Disaster Prevention and Mitigation
DHWL	Design High Water Level
DOH	Department of Highway
DWR	Department of Water Resources
EIA	Environmental Impact Assessment
EDC	Eastern Diversion Channel
EL	Elevation Level
FS	Feasibility Study
FEM	Finite Element Method
IC	Interchange
JICA	Japan International Cooperation Agency
JICA MP	Authorized Comprehensive Flood Management Plan
MNRE	Ministry of Natural Resources and Environment
MOAC	Ministry of Agriculture and Cooperatives
MOT	Ministry of Transport
MSL	Mean Sea Level
n	Roughness Coefficient
NESDB	National Economic and Social Development Board
NWRC	National Water Resources Committee
ONWR	Office of the National Water Resources
psu	Practical Salinity Unit
PVD	Prefabricated Vertical Drain Method
RR	Ring Road
RID	Royal Irrigation Department
SCC	Soil Cement Column Stabilization
SCWRM	Strategic Formulation Committee for Water Resources Management
TSP	Total Suspended Particulates
WFMC	Water and Flood Management Committee

CHAPTER1 OUTLINE OF THE STUDY

1.1 Background

The Chao Phraya River Basin (hereinafter, “the Basin”), which occupies about one-third of the total land area of the Kingdom of Thailand, received benefits of overflows for the agriculture through frequent floods in the past. However, mitigation of floods risks has become an urgent issue due to the urban development. As a result of rapid economic growth, the landscape has drastically changed as more properties and assets in potential flood areas have been developed by private sectors. During the severe flood in 2011, seven industrial estates in the north of Bangkok were inundated, with 469 Japanese companies affected by this severe flood. The economic loss was estimated at approximately THB 1,400 billion.

Japan International Cooperation Agency (JICA) and the Crown Property Bureau (CPB) prepared flood control measures for the Basin in 1999 – 2000. However, the measures were implemented only for the lowest part of the Chao Phraya River (hereinafter, “the River”) because of the influence of the Asian currency crisis and other constraints. After the severe flood in 2011, JICA prepared the Comprehensive Flood Management Plan for the Chao Phraya River Basin (hereinafter, “the Master Plan”) upon the request of the Royal Thai Government (hereinafter, “the Government”). JICA summarized and submitted the Final Report in June 2013.

Due to the change of government in Thailand, The Outer Ring Road Diversion Channel, river improvement works (including Tachin River refurbishment), and Ayutthaya bypass have not been completed. Regarding efficiency improvement of existing dams, although efforts are also being conducted in RID, no large scale floods have occurred since 2011. Therefore, adequate analysis have not been able to be conducted.

The JICA team aware that part of the "Dyke raising of the lower the Chao Phraya River" proposed in the master plan has already been implemented. Also, Ayutthaya bypass has been completed up to the Detail Design, but the JICA Study Team has repeatedly pointed out that the order of project implementation is incorrect.

However, the implementation of the Outer Ring Road Diversion Channel has been planned by the Royal Irrigation Department (RID) with the concept to conduct the integrated development of the Diversion Channel (hereinafter, “the Channel”) proposed in the Master Plan and the Outer Ring Road (hereinafter, “the Outer Ring Road”) in cooperation with the Department of Highways (DOH) under the Ministry of Transport (MOT). In August 2016, the Government requested JICA support to conduct a Pre-Feasibility Study (Pre-FS) to analyze the feasibility of the concept of RID’s integrated development plan.

Upon the request, JICA dispatched the JICA Mission to conduct an initial survey in the beginning of September 2016. The JICA Mission identified the issues and challenges in discussions with RID, based on initial findings through the surveys. The identified issues and further steps are as follows:

i. Preparation of a basic plan, which integrates the Outer Ring Road of DOH and the Diversion Channel of RID prior to the FS,
ii. Analysis of efficient usage of the Diversion Channel in the dry period,
iii. Proposal for the optimum scale of the Diversion Channel along with the Outer Ring Road,

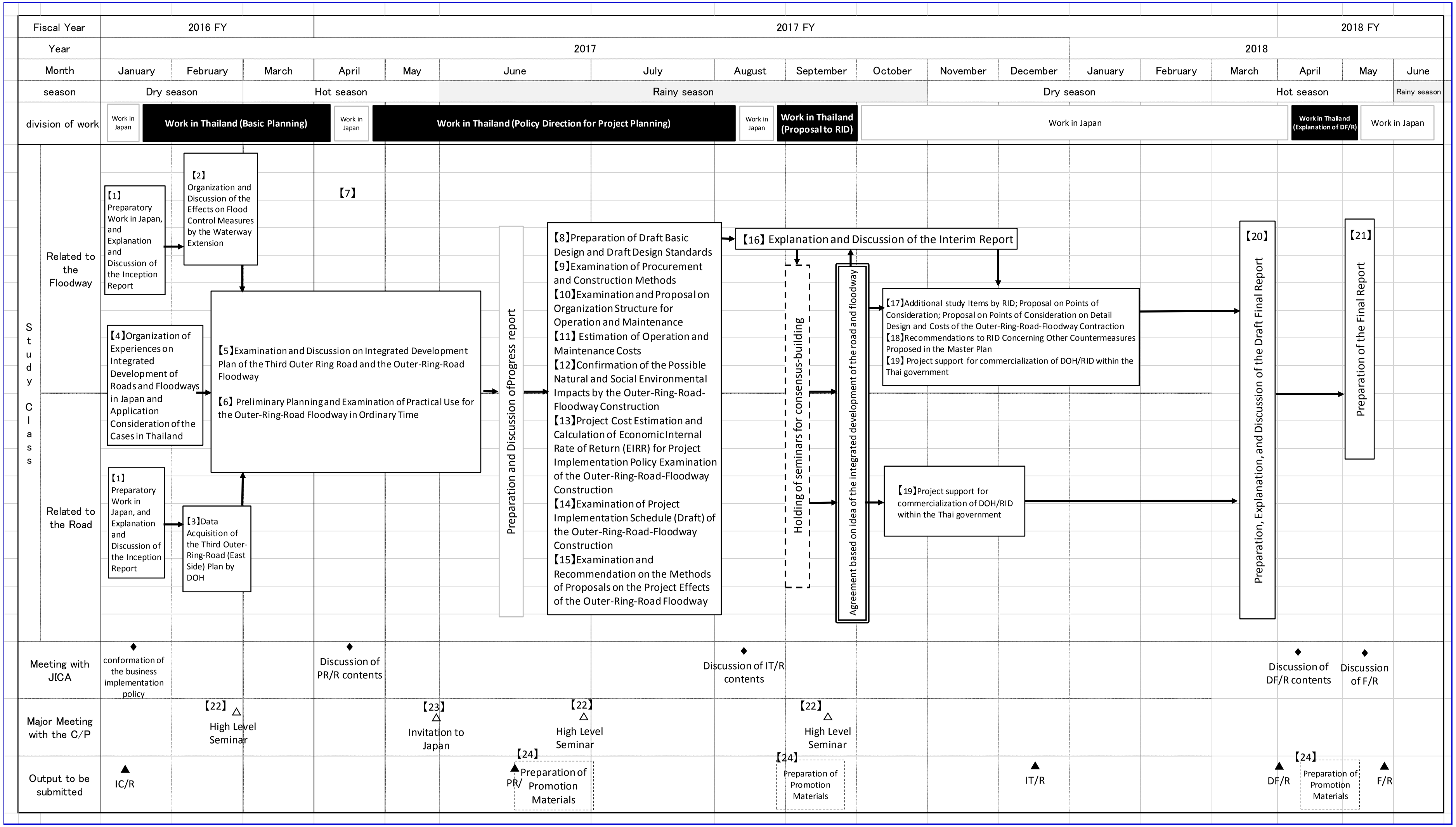
- iv. Confirmation of mutual understanding of the importance of basic surveys and analyses prior to the FS, and
- v. Provision of the mutual agreement between DOH and RID on the implementation of the basic plan for the integrated development of the Outer Ring Road with the Outer Ring Road Diversion Channel projects by September 2017.

1.2 Objectives of the Study

Objectives of the Study are: (i) to develop a basic plan of the implementation of the Outer Ring Road and the Diversion Channel as a pre-phase of the FS, (ii) to identify necessary survey items and points of concern to carry out additional studies and (iii) to collect necessary information and conduct further studies/analyses for the integrated development.

1.3 Schedule and Current Situation

The work schedule is shown in Figure 1.3.1.



Source : JICA study team

Figure 1.3.1 Project flow chart

1.4 Overall Activities

Three High Level Seminars were held with objective to appeal advantage and possibility of combined project of the Outer Ring Road (East section) and the Diversion Channel. In May 2017, members of the counterparts of the project were invited to Japan to encourage their understanding for the combined project of the Outer Ring Road and the Diversion Channel, through introducing Japanese experiences and knowledge. In Thailand, meetings with RID and DOH had been held, as well as with the Department of Water Resources (DWR). DWR is the secretariat of the National Water Resources Committee (NWRC) to which RID shall report the decision of the project prioritization. The activities are described below.

1.4.1 Implementation of the High Level Seminars

The objectives of the seminar were to present the Diversion Channel project to NWRC whose chairman was the prime minister of Thailand, and to appeal advantage and possibility of the combined project of the Outer Ring Road (East section) and the Diversion Channel.

At the beginning, it was supposed to be held after certain level of data collection, technical consideration and proposal on RID plan related to the Outer Ring Road Diversion Channel which was proposed by JICA MP had done. However, since consideration of construction of the Diversion Channel integrated with the Outer Ring Road Plan, which was prepared by DOH, was needed, and the agreement on the basic plan between DOH and RID should be made before September 2017 due to the DOH schedule, thus the 1st High Level Seminar had been accelerated to be in February 2017. The 2nd and the 3rd High Level Seminars were held subsequently on June 28 and September 14, 2017.

Table 1.4.1 Outline of High Level Seminars

Date	Objectives and Contents	Participants
February 27, 2017	The 1st High Level Seminar Objectives： 1) To share Japanese experience on integrated development of Road and Dikes 2) To share analysis by the JICA Study Team on integrated development of the Outer Ring Road with the Diversion Channel 3) To confirm way forward by participants Contents： ・ Outline of the JICA Flood Management and Mitigation Projects in Thailand ・ Outline of the Outer Ring Road ・ Necessity of the Outer Ring Road Diversion Channel and Current Study of Flood Management for the Chao Phraya River ・ Japanese Experience on integrated development of Road and Dikes	84

	・ Analysis by the JICA Study Team on the integrated development of the Outer Ring Road with the Diversion Channel and the way forward	
June 28, 2017	The 2nd High Level Seminar Objectives： 1) To share analysis by the JICA Study Team on integrated development of the Outer Ring Road with the Diversion Channel 2) To have discussions on the analysis by the JICA Study Team 3) To confirm the way forward by participants Contents： ・ Summary of Study Result ・ Integrated Alignment of Road Combined Diversion Channel ・ Structural Analysis and Integrated Cross Section of Road Combined Diversion Channel ・ Wrap-up Discussions	80
September 14, 2017	The 3rd High Level Seminar Objectives： 1) To share analysis by the JICA Study Team on integrated development of the Outer Ring Road with the Diversion Channel 2) To have discussions on the basic plan and implementation plan by the JICA Study Team 3) To confirm the way forward by participants Contents： ・ Summary of Pre-Feasibility Study ・ Implementation Plan of Road Combined Diversion Channel －Basic Design and Structure ・ Implementation Plan of Road Combined Diversion Channel －Construction Plan and Project Evaluation ・ Wrap-up Discussions	83

Source: JICA Study Team

(1) The 1st High Level Seminar

JICA, RID and DOH co-organized the Seminar on February 27, 2017, at Westin Grande Sukhumvit, Bangkok. There were 84 participants from MOT, DOH, Ministry of Agriculture and Cooperative (MOAC), RID, NESDB, Office of Natural Resources and Environmental Policy and Planning (ONEP) and others attended the Seminar.

The Japanese Embassy's Minister, MOT's Vice Minister and RID's DG gave the opening remarks.

Professor Kimio Takeya, JICA's Distinguished Technical Advisor to the President, presented the background of the flood control plan in the Chao Phraya River Basin and the main points of the authorized Comprehensive Flood Management Plan for the Chao Phraya River Basin studied by JICA. He then explained the concept of the authorized Comprehensive Flood Management Plan for the Chao Phraya River Basin and the integrated development of the Outer Ring Road with the Diversion Channel as an alternative for flood mitigation downstream from Ayutthaya. Prof. Takeya later emphasized that this Diversion Channel was a necessary structural measure of flood protection for Thailand's economic areas.

Prof. Takeya also introduced that the idea of the integrated development of the Outer Ring Road with the Diversion Channel was proposed in the full menu of the Master Plan (M/P) by the Strategic Formulation Committee for Water Resources Management (SCWRM) in 2011. He further explained that the Outer Ring Road would function as a flood bund to protect Bangkok, but when constructed independently without a diversion channel, it would make new uncontrolled inundation areas outside the Outer Ring Road. In this connection, Prof. Takeya emphasized the necessity of the integrated development of the Outer Ring Road with the Diversion Channel to prevent creation of the new uncontrolled inundation areas.

DOH's representative explained the necessity and importance of the Outer Ring Road.

RID's representative explained that the integrated development of the Outer Ring Road with the Diversion Channel was studied with support from JICA in accordance with the cabinet resolution, and explained the progress of "Current Study of Flood Management for the Lower the Chao Phraya River". It is thought that is prototype of "RID 9 projects".

The JICA Study Team's Deputy Project Manager introduced the practical experience of the successful integrated development of the flood control channel and road in Japan in order to convince that the cooperation between DOH and RID for this integrated development was necessary. The JICA Study Team's Project Manager explained the concept of the Integrated Development for the Outer Ring Road with the Diversion Channel, and pointed out the advantages of the integrated development on cost reduction, utilization of the excavated soils, less environmental and social impacts.

DOH's Chief Engineer expressed his appreciation and intention to fully collaborate with RID for the achievement of the implementation of the integrated development project.

RID's Deputy Director General expressed his gratitude to all participants and committed to fully support this Integrated Development.

(Attached: Seminar Program and Q&A)

Source: JICA Study Team

Photo 1.4.1 The 1st High Level Seminar

(2) The 2nd High Level Seminar

On June 28, 2017, the 2nd High Level Seminar was held at the ballroom of Westin Grande Sukhumvit Hotel. The seminar was attended by 80 participants from MOT, RID, DOH, NESDB, DDPM, NWRC, DWR and others.

The opening speeches were given by the Ambassador of Japan and Minister of MOT, followed by presentations by Prof. Kimio Takeya and Mr. Junji Miwa from JICA.

In the speech, Minister of MOT expressed his expectations for this seminar, which would provide the study results and discussion on the flood prevention measures in Thailand and would become a good opportunity to consider the future measures since the economic and social damage and losses by the floods were extensive.

Prof. Kimio Takeya, JICA's Distinguished Technical Advisor to the President, explained the importance of swift implementation of the flood prevention measures for the Chao Phraya River based on the flood damage data of the flood in 2011 and the feelings of Japanese companies who were expecting to work together with people of Thailand. He emphasized the needs of diversion channel to protect the economic center from floods and to find out effective measure with best combination of structure measures and non-structure measures to control the floods. In addition, it was expressed that Japan respects knowledge and experience of Thailand and to support and work together to find out the best measures based on Japanese experience. At last, he proposed "what should Thailand think now" for aiming the country to become safe and resilient against floods.

Mr. Junji Miwa, a senior advisor of JICA, explained the outline of the actual study result. At first, he showed the benefits of integrated project which were confirmed in the Working, and explained the concept of the four cases which were used in consideration for the alignment of the diversion channel. After showing the criteria of evaluation for the comparison of the four cases, he explained the outline of each case. At last, outline of the evaluation was explained.

In the later, JICA Study Team explained the details of the study result on the alignment and structural analysis of integrated project of the Outer Ring Road and Diversion Channel.

In the presentation No. 1, followed the explanation of contents of evaluation items and soil test results, the Team explained the cross sections related to each alignment of the diversion channel. The suitability of Case 2 was explained with its current results. Also, utilization of the river terrace was shown as an example for utilization of the diversion channel during non-flood time.

In the presentation No. 2, three types of standard cross sections which were designed based on the soil test results were shown and explained in detail. It was presented that the idea of using excavated soil from the diversion channel to be utilized for road embankment has been considered.

The contents of the session, questions and answers were shown below.

Q1: From RID

In 2011, the maximum flow rate was about 4,000 m^3/s. If only the Outer Ring Road with the Diversion Channel is constructed, is it possible to fully protect the flood? Does the JICA Study Team consider this situation?

A1: By the JICA Study Team

The JICA Study Team has already investigated the flood in 2011. In case the capacity of the Diversion Channel is 500 m^3/s, the economic area can be protected, but some inundation areas in upstream will still remain. The Outer Ring Road and the Diversion Channel is considered as the high priority measure to be implemented.

Q2: From RID

In the dry season, the water level is low. How to maintain the water level in the channel? Does the JICA Study Team consider this? Is there any study for irrigation?

A2: By the JICA Study Team

Main propose of this study is the flood protection. Irrigation will be considered in the further study. In future, the gates at the crossing points may be used to maintain the water level in the Diversion Channel. At present, the irrigation area is divided into 7 sub-areas with the gate across the Diversion Channel at each area to maintain the water level for irrigation. The water level is to be maintained at 4-5 m. This concept is still being studied.

Q3: From DOH (Suggestion)

Actually, DOH has considered the new alignment same as Case 3 and Case 4 to avoid the land acquisition. But the alignment in Case 3 is better. There are a lot of advantages such as transportation because it passes through many communities.

Q4: From RID

Did the JICA Study Team already define the minimum water level to be maintained?

A4: By the JICA Study Team

This study emphasizes in the flood protection. Irrigation will be considered in the further study but it must not disturb the function of existing channels. If there is a standard for maintain water level, the Study Team will follow that standard. This idea will be considered in the future.

Q5: From RID

The intrusion to the flood plain will definitely occur in the future. Who owns this flood plain and maintain this flood plain? Who can get the benefit from this flood plain?

A5: By the JICA Study Team

The flood plain is between embankments. For this case, the JICA Study Team thinks that this is also a part of the Diversion Channel. Therefore, the government offices who are in charge of the Diversion Channel will own this flood plain. In Japan, the government offices who are in charge in the flood management will own this land. However, this also depends on the regulation in each province. If someone wants to use this land, they have to ask for permission from that province.

Q6: From DDPM

Did the JICA Study Team consider the sea water protection in agricultural area?

A6: By the JICA Study Team

In this Study, there will be a gate at the river mouth for sea water protection. For irrigation (agricultural area), it will be considered in the future.

Q7: From RID

This Diversion Channel runs through a flat area. How to set up the slope? How to excavate the river? And How to manage the crossing points?

A7: By the JICA Study Team

In the flood period, the water can flow by gravity. The flow rate depends on the sea water level. If the sea water level is high, the flow rate is low. If the sea water level is low the flow rate is high. From the calculation, the water can flow at 500 m^3/s. The height of embankment is higher than water level (from calculation). Therefore, it can protect water from flooding.

Q8: From RID

There are many existing rivers in the area which are passed by the Diversion Channel. In the flood period, local inhabitants also want to drain the water but the water level in the natural rivers or irrigation channels is lower than water level in the Diversion Channel. How to manage this issue? Is it necessary to install pumps?

A8: By the JCIA Study Team

The study area is the Chao Phraya River basin. How to drain the water from the Chao Phraya River basin? The internal drainage for each area is not our main scope. We need to cooperative with RID to discuss on the water management plan.

Q9: From RID

The crossing point is very important. For example, the Eastern Diversion Channel project (Pasak – Gulf of Thailand project) uses the siphon at crossing point to maintain the function of existing channel. For sea level, the Study Team uses the high tidal level at 2 m in the calculation but for the Eastern Diversion Channel use 2.5 m. Which one is the correct value?

A9: By the JICA Study Team

The sea level which the Study Team used is the data at an observation station at the river mouth in 2011. But it depends on tidal variation also. The Study Team will consider this issue from now on.

Based on the above discussions, Chief engineer of DOH mentioned that the reduction of the costs was possible by the integrated project and it could be expected for the reduction of inundation damage to the roads by flooding. Effective utilization of diversion channel area could also be expected. However, the consideration of the discharge water capacity of the diversion channel was requested in a nod to situation during dry season and wet season.

RID’s Deputy Director General commented that RID reported two projects to the cabinet. One of them was this project. The effectiveness, implementation term and operation plan were also needed to explain to the Cabinet. From the presented four cases, RID considered that Case 2 was most appropriate. Therefore, RID requested to the JICA Study Team to study of the followings after this seminar; i) standard cross section of the diversion channel, ii) alignment of the road and diversion channel, and iii) practical operation plan. The plan would be possibly submitted to NWRC when the details were presented clearly.

The seminar’s agenda, questions and answers is attached in the Appendix.

Source：JICA Study Team

Photo 1.4.2 The 2nd High Level Seminar

(3) The 3rd High Level Seminar

On September 14, 2017, the 3rd High Level Seminar was held at the ballroom of Westin Grande Sukhumvit Hotel. The seminar was attended by 83 participants from MOT, RID, DOH, NESDB, DDPM, NWRC, DWR etc.

Firstly, the opening speeches were given by Minister-Economic Sector of Embassy Japan and Minister of MOT, followed by presentations by Prof. Kimio Takeya and Mr. Junji Miwa from JICA.

Prof. Kimio Takeya, JICA’s Distinguished Technical Advisor to the President, emphasized to work together for flood control measures through utilizing Japanese experience with respect of the experience and knowledge of Thailand. He explained the characters such as largeness the Chao Phraya River basin and mild sloop of the river. And also since the river was utilized and prepared as irrigation use, it was difficult to expand the river channel for flood control anymore, and some part of the flood area should be allowed for inundation. Therefore he mentioned that the priority project of the Master Plan should be accelerated, and he emphasized that the acceleration of the best mix of structure and non-structure measures is most prioritized matter.

Mr. Junji Miwa, a senior advisor of JICA, explained the outline of the study result and the outline of the detailed study about the selected route from the 4 routs which had proposed in the 2nd High Level Seminar. In addition, he explained about the result of project effectiveness, and also explained that the project is feasible from the view point of cost effectiveness.

After the above introduction, JICA Study Team explained details of the study. The Study Team explained typical cross section, construction method and utilization of excavated soil, etc., in accordance with the soil condition.

After the presentations, Question and Answer session was held.

Question 1 from DOH

DOH realize that diversion channel project is very important because it can reduce the damage from flooding in the future. However, it not yet convincing for the advantage of combine diversion channel and road together. The Diversion Channel and Outer Ring Road just attached together.

1. Construction cost will be higher
2. Right of way reduce
3. Public impact is higher

It is better to run the project separately. It is easy to get a permission if we run project separately. The construction time may be shorter.

Answer 1 from JICA Study Team

1. We understand your concern. If the diversion channel is combined, the construction method will change. We are considering the way that has a small effect to the road construction method.

2. If we construct both project together, the construction cost will be 83 million baht. Now, if DOH construct only, the construction cost will be 81 million baht. Since the structure of interchange is changed, the cost of interchange will be increased.

If we separately construct of the two projects, the cost is still the same. However, we have to discard of the soil approximately 10 million tons. RID have to take care of the waste soil. The excavated soil can be reduced by combining these two projects together. The possibility of utilization of excavated soil for construction of embankment of the road is examined.

EIA process of the road project had already started. Permission request for Diversion channel will be implemented in parallel with the road. Therefore, it will not disturb the DOH process.

Question 2 from DOH

We are interested in the method which is recommended by JICA Study Team. Normally, balance back fill method is used for road construction. Is it possible to decrease a depth of diversion channel? JICA Study Team considers only construction cost. But, the benefit term of integrated project should be considered. Then the value of this project will increase. JICA Study Team should propose an advantage of flood plain more because this area will be prepared by land acquisition. How will the flood plain area be utilized every season? It can be a new landmark of Thailand.

Answer 2 from JICA Study Team

Japanese method of construction stage will be mentioned in the report. If we reduce the depth of diversion channel, the width will be increase a lot. It is not effective. We will propose the best alternative to protect the flood. This is our main objective at first. Actually, the advantage of this project is protect and reduce the effect from flood. For flood plain, we need more information from government agency in Thailand because they have more experience about land use than our expert. Some idea is to build a hotel or temporary market.

Question 3 from RID

We think that the project have to run together both Ayutthaya by pass and outer ring road. These two project have to run parallel.

Answer 3 from JICA Study Team

We use the information from big flood in 2011. We agree with the RID's idea that we have to run both project together.

At the end of the Seminar, RID's Deputy Director General concluded the speech saying that though the Japanese consulting capacity is able to be trusted, since there are several project in this area, the condition will be changed by the situation. Therefore RID will continue the consideration. When RID starts the project, RID will do the FS.

The seminar's agenda, questions and answers is attached in the Appendix.

Source : JICA Study Team

Photo 1.4.3 The 3rd High Level Seminar

1.4.2 Invitation of Thai stakeholders to Japan

(1) Background and Objective of Invitation

RID and DOH are collaborating on the integration of the Outer Ring Road (East section) and the Outer Ring Road Diversion Channel based on the JICA MP.

In accordance with this, relevant government agencies to this project were invited to Japan from MOAC, MOT, NWRC, RID, DOH and DWR. In order to have a better understanding on the practical integrated development of Road and Diversion Channel in Japan and to share the knowledge among participants, activities were set up with the purposes as follows;

- Promoting the understanding of Thai stakeholders to Japanese technology and experience and building a good relationships with Japanese stakeholder.
- Introducing the cases and discussing about integration of Road and Diversion Channel
- Creating an opportunity to activate the project of the integration

(2) Schedule

The schedule was as follows;

Date	Time	Activity	Destination
May 28 (Sun)		Flight to Japan（Bangkok→Tokyo）	
May 29 (Mon)	09:30-10:00	Visit to JICA HQ ・Courtesy by JICA、briefing	JICA headquarter
	10:30-12:00	Visit to Water and Disaster Management Bureau of MLIT ・Courtesy ・Induction of river affairs in Japan	Visit Water and Disaster Management Bureau of MLIT
	14:00-17:00	Field inspection of projects by Metropolitan Expressway Company Limited ・site visit at Shakujii River ・site visit at Arakawa river Naka-Tei	Metropolitan Expressway Company Limited
May 30 (Tue)	10:00-11:30	Visit to Kanto Regional Development Bureau ・Plan of soil volume balance of excavation and embankment ・Command Center of Disaster Management	Kanto Regional Development Bureau of MLIT
	14:00-17:00	Field inspection of projects by River Office of upper Arakawa-river ・No.1 Flood control reservoir ・Transverse dike ・Saitama banking ・Stock yard	River Office of upper Arakawa-river of MLIT
May 31 (Wed)	09:00-11:00	Visit to Kinu River ・Explanation of the dike break and rehabilitation project	River Office of Shimodate-River of MLIT

		・Machinery for soil improvement	
	12:30-13:30	Visit to Technical Center of Pacific Consultant Co., Ltd (PCKK) ・Hydraulic experiment facility increase of water level by piers	PCKK
	14:00-16:00	Visit to Public Works Research Institute (PWRI) ・Lecture of soft ground measure in Japan ・Large-scale three-dimensional shaking table	PWRI
June 1 (Thu)	09:00-11:00	Visit to Diversion Channel of Ayase River and Tokyo Outer Ring Road ・introduction of Integrated project for diversion channel and road (issues during construction, and on actual situation)	River Office of Edo-river of MLIT, Office of Kitasyuto Express way
	14:00-16:00	Visit to JICA Ichigaya ・Discussion on the basic concept of Outer Ring Road Diversion Channel	JICA Ichigaya
June 2 (Fri)		Flight to Bangkok（Tokyo→Bangkok）	

(3) Invitees

Invitees were as below.

	Ministry/Organization	Department	Office	Designation	Ms./Mr.	Name
1	Ministry of Agriculture and Cooperatives (MOAC)	Office of permanent secretary	-	Deputy Permanent Secretary	Mr.	Mr. Lertviroj Kowattana
2	Ministry of Agriculture and Cooperatives (MOAC)	Office of permanent secretary	-	Director of Project Planning 2	Mr.	Mr. Chumlarp Tejasen
3*	Ministry of Agriculture and Cooperatives (MOAC)	Royal Irrigation Department (RID)	-	Deputy Director General for Engineering	Mr.	Dr. Somkiat Prajamwong
4	Ministry of Agriculture and Cooperatives (MOAC)	Royal Irrigation Department (RID)	-	Expert on Planning	Ms.	Dr. Phattaporn Mekpruksawong
5	Ministry of Agriculture and Cooperatives (MOAC)	Royal Irrigation Department (RID)	Office of Engineering and Architecture Design	Senior Expert on Civil Engineering (Design)	Mr.	Mr. Phichet Ratanaprasatkul
6	Ministry of Transport (MOT)	Office of permanent secretary	-	Chief of Inspector General	Mr.	Mr. Voradej Harnprasert
7	Ministry of Transport (MOT)	Department of Highways （DOH）	-	Chief Engineer for Location and Design	Mr.	Mr.Pramon Sathapornnanon

8	Ministry of Transport (MOT)	Department of Highways （DOH）	Bureau of Planning	Civil Engineer Senior Professional Level	Mr.	Dr.Kitti Subprasom
9	Ministry of Transport (MOT)	Department of Highways （DOH）	Bureau of Location and Design	Civil Engineer Professional Level	Mr.	Mr.Pichakorn Srijanthong
10	National Water Resources Committee (NWRC)	Office of the Secretariat of National Water Resources Committee	-	Acting Director	Mr.	Mr. Kanapoj Wandee
11	National Water Resources Committee (NWRC)	Office of the Secretariat of National Water Resources Committee	Water crisis Prevention Center	Director	Mr.	Mr. Satit Sueprasertsuk
12	Ministry of Natural Resources and Environment (MNRE)	Department of Water Resource	Water Resources Regional Office 2 (Saraburi Province)	Director	Mr.	Mr. Anek Chompanich

*：Minister of MOAC had participated until May 30, 2017

(4) Activity (in summary)

Date	Activity	Objective
May 29 (Mon)	Visit to JICA HQ ・Courtesy briefing	
	Visit to Water and Disaster Management Bureau of MLIT ・Courtesy ・Induction of river affairs in Japan	・Courtesy call ・Promote the understanding of cases in Japan
	Field inspection of projects by Metropolitan Expressway Company Limited ・replacing site visit at Shakujii River ・Site Visit at Arakawa river Naka-Tei	・understanding the effectiveness and issues of integrated project of river and road in Japan
May 30 (Tue)	Visit to Kanto Regional Development Bureau ・Plan of soil volume balance of excavation and embankment ・Command Center of Disaster Management	・Understand the importance of soil volume balance for construction plan ・Understand a case of operation for flood measure
	Field inspection of projects by River Office of the upper Arakawa-river ・No.1 Flood control reservoir ・Transerse dike ・Saitama banking ・Stock yard	・Promote the understanding of technique of soil improvement （measure for soft ground as future issue） ・Understand utilization of excavation soil
May 31 (Wed)	Visit to Kinu River ・Explanation of the dike break and rehabilitation project ・Machinery for soil improvement	・Promote the understanding of the plan and method of dike maintenance ・Promote the understanding of soil improvement

	Visit to Technical Center of Pacific Consultant Co., Ltd (PCKK) ・Hydraulic experiment facility increase of water level by piers	・Promote the understanding of Japanese hydraulic model for discussion of Diversion Channel
	Visit to Public Works Research Institute (PWRI) ・ Lecture of soft ground measure in Japan ・ LARGE-SCALE THREE-DIMENSIONAL SHAKING TABLE ・Geotechnical Centrifuge	・Promote the understanding of soft ground management in Japan
June 1 (Thu)	Visit to Diversion Channel of Ayase River and Tokyo Outer Ring Road ・introduction of Integrated project for diversion channel and road （Issues during construction, and on actual situation）	・Promote the understanding of integration project of Road and Diversion Channel in Japan
	Wrap-up meeting ・Discussion on the basic concept of Outer Ring Road Diversion Channel	・wrap up, discuss the basic concept of Outer Ring Road Diversion Channel

(5) Main conclusion of the discussion

The integrated development of the Outer Ring Road Diversion Channel, the structure of the Diversion Channel and the Outer Ring Road, and rough cost estimation of construction was exhibited by JICA Study Team. All the above mentioned topics were discussed. The contents and pre-working scope for the next High Level Seminar between JICA and the invitees was mutually agreed. The followings are the results from the wrap-up session.

<Discussion results of the wrap-up session>

1. Schedule
    - The date of the next High Level Seminar was proposed to be June 28 (Wed), 2017.
    - Minister of Transport, Mr. Arkom Termpittayapaisith, and Minister of Agriculture and Cooperatives, General Chatchai Sarikulya would be invited by JICA Thailand Office.
    - Pre-working on the presentation in the seminar would be held about 1 week before the seminar.
    - Schedule of the Pre-working was set on June 22 (Thu) or 23 (Fri), 2017.
    - Participants of Pre-Working were
        - RID : Representatives who attended the site visit in Japan and the counterparts.
        - DOH : Representatives who attended the site visit in Japan.
2. Discussion contents in the High Level Seminar
    (1) Alignment proposal and their comparison (4 Cases)
    (2) Proposed cross section type of Road and Diversion Channel, and estimation of construction cost (4 Cases)
    (3) Proposed implementation schedule
3. Future work plan
    (1) Alignments and their comparison (4 Cases)

A total of 4 cases were proposed and their information were summarized including cost for land expropriation, rough estimation of construction cost, number of houses for resettlement, hydrologic condition, alignment of road facilities such as the interchanges, and environmental and social examination.

Case 1 : Diversion Channel was set up along the current plan of the Outer Ring Road

Case 2 : Diversion Channel was set up along the current plan of the Outer Ring Road, but some parts were deviated to reduce the number of houses for expropriation.

Case 3 : Diversion Channel was set up along the current plan of the Outer Ring Road, but some parts were deviated to minimize the number of houses for expropriation

Case 4 : The Outer Ring Road was relocated to the alignment of the Diversion Channel in Case 3.

(2) Cross section of the Diversion Channel and the Outer Ring Road, and estimation of their construction cost (4 cases)

① Consideration of soil condition

Part was divided according to the soil condition with respect to the thickness of Bangkok Clay published by Kasetsart University. An appropriate reinforcement method would be proposed for typical section.

② Rough estimation of construction cost

- For the Diversion Channel and the Outer Ring Road, cost was estimated by parts.
- For road facilities, cost was estimated based on typical section of the interchanges of main crossroads.

③ Flood plain

Construction of the flood plain inside the Diversion Channel was discussed by taking into consideration of the following points:

✧ Flood plain would be utilized efficiently, but not as the main road,

✧ Utilization of flood plain in Japan would be considered as prototype.

1.4.3 Meeting with the related organizations

(1) Inception Discussion

The inception discussion was held together with the related agencies such as NESDB, DOH and DWR and others, at 10:00 AM on January 31, 2017. In addition, the explanation of the summary of the project to high level officers of DOH at 9:00 AM and NESDB at 5:00 PM on February 1, 2017. The contents of the Study were understood by the participants and the cooperation to the Study by the participating agencies was confirmed through the inception discussion.

Source: JICA Study Team

Photo 1.4.4 Inception discussion

(2) Meeting with DOH (March 2017)

The possibility to construct the Outer Ring Road and the Diversion Channel together as a combined project is discussed. DOH quoted “land acquisition will become difficult if the combination requires larger area of land, which may be a huge problem in execution. If the Diversion Channel is only built for flood control, land acquisition would be difficult. Therefore, irrigation function should also be added to it.” For this issue, JICA explained that, from the beginning stage of the MP, the purpose of the Diversion Channel has been assumed to be for flood control only. DOH pointed out more issues as follows.

- Soil in the target area is extremely soft which caused slope failures during excavation of Suwannabhumi Airport Drainage Channel. Thus the same problem may happen to the combined project.
- EIA has been finished and it is only for the Road Planning, therefore update and complement for the whole combined project will be needed. It is necessary for RID to make confirmation with relevant Ministries and Agencies whether the existing EIA needs to be revised.

It is necessary to design the treatment plant or destination for the residual soil based on geological survey.

(3) Meeting with Ministers before the 2nd High Level Seminar

1) Ministry of Agriculture and Cooperatives (MOAC): Minister Gen. Chatchai Sarikulya

On June 27, 2017, 3:30 PM, the presentation contents of the 2nd High Level Seminar were explained to Minister Gen. Chatchai Sarikulya. The contents were agreed.

Source：JICA Study Team

Photo 1.4.5 Meeting with the Minister Gen. Chatchai Sarikulya, MOAC

2) Ministry of Transport (MOT): Minister Mr. Arkhom Termpittayapaisith

On June 28, 2017, 10:30 AM, the presentation contents of the 2nd High Level Seminar were explained to Minister Mr. Arkhom Termpittayapaisith. The contents were agreed.

Source：JICA Study Team

Photo 1.4.6 Meeting with the Minister Mr. Arkhom Termpittayapaisith, MOT

(4) Progress Report Meeting

On July 4, 2017, meeting for the Progress Report was held.

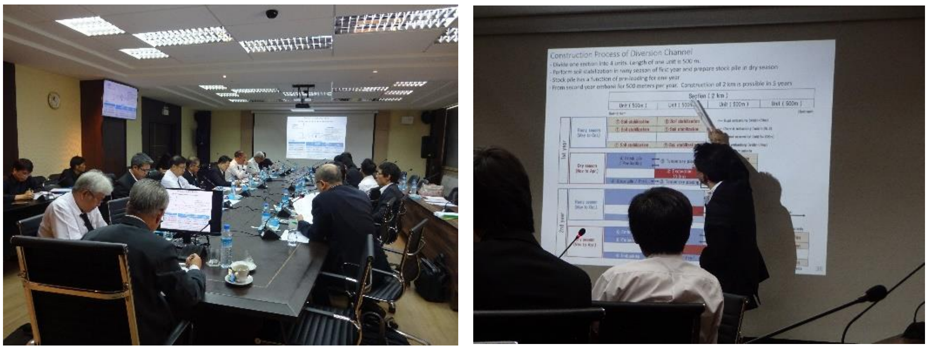
JICA Study Team explained further the results from detailed study following the 2nd High Level Seminars and had discussions with counterparts on more practical contents. The questions from counterparts were focusing on operation issues, mainly on water volume control for existing channels, control of saltwater concentration near river mouth, and issues regarding the maintenance, etc.

Source：JICA Study Team

Photo 1.4.7　Progress Report meeting

(5) Interim Report Meeting

On September 20, 2017, a meeting for Interim Report was held. JICA Study Team explained further contents of the study result following the 3rd High Level Seminars and had discussions with counterparts on more practical contents. Counterparts and JICA Study Team discussed enthusiastically on the measures for soft clay and utilization of the excavation soil.



Source：JICA Study Team

Photo 1.4.8　Interim Report meeting

(6) Meeting with DOH (October 2017)

Three methods were proposed by JICA Study Team for DOH to reduce the construction cost of the combined project of the Outer Ring Road and the Diversion Channel. The first one (Type A) is to share the road as a dike of the Diversion Channel; the second one (Type B) is to lower the road level; and the third one (Type C) is to implement both. DOH's opinion indicated that only Type B was possible because sharing the Road as a dike was not appropriate especially in management. Furthermore, other issues were illustrated by DOH. For example, it was also necessary to clarify how the combined project could promote development and bring a long-term benefit for nearby areas such as building the service areas to be sightseeing spots. It would be preferable for DOH if the alignment of the Diversion Channel came along to the road alignment planned by DOH, or it would be much inconvenient for local residents with the service road on the other side of the Channel, which would be uneconomic as well. Still, land acquisition might become a difficult problem.

(7) Meeting with RID (October 2017)

A meeting was organized by the Minister of MOAC on October 27, 2017.

The Minister of MOAC, as chairman, held the meeting. As a preparation step to carry out the flood management plan, this meeting focused on determining the priority projects. Over 50 participants attended this meeting, including the officials from RID and DWR, researchers, and engineering consultants.

RID introduced 9 on-planning projects to the meeting, and 4 of them, namely Ayutthatya Bypass (AB), Chainat Pasak (CP) + Eastern Diversion Channel (EDC), the Outer Ring Road Diversion Channel (DC), and Ta Chin River Project. RID asked for researchers' opinions about priorities of these projects. (Researchers and professors from local universities were mainly asked.)

Mr. Tanaka, the head officer of JICA Bangkok Office, then introduced that seeing the deluge in 2011 made numerous damage on this country, JICA had carried out a technical Master Plan (MP) for flood management targeting on flood with 100-year-return period. Furthermore, as a next step, a Pre-Feasibility Study (Pre-FS) is now on going for the DC project whose priority is considered as the highest by JICA.

However, in the view of the Minister of MOAC and RID, project AB should have the highest priority and project CP was the next. The meeting did not give a solid conclusion, so the need of further discussion was still remained.

Source : JICA Study Team

Photo 1.4.9 Meeting with RID (October 2017)

(8) Meeting with RID (November, 2017)

Subsequent meeting was held on November 15 and 16, 2017. Dr. Somkiat Prajamwong, RID's Deputy Director and other officials had participated.

JICA created the Authorized MP focusing on reducing the flood damage in Bangkok and Ayutthaya area where residents, assets and industrial clusters are centered.

On the other hand, JICA presumes that RID gives priority to the protection of urban areas of Ayutthaya and surrounding farmlands. Regarding Ayutthaya bypass, Detail Design is completed by RID, but "countermeasures should be implemented from downstream" is the first rule of flood countermeasure, because of this the prior improvement of the Outer Ring Road Diversion Channel located downstream of Ayutthaya bypass is indispensable. JICA repeatedly points out that the Ayutthaya bypass precedence is incorrect.

In addition, since the process of 1.setting of the planning scale for flood countermeasure, 2.calculation of Basic Discharge for flood, 3. setting of countermeasure plan, 4. setting of Design discharge for flood, is not indicated. For this reason JICA Study Team described that RID plan is not based on engineering judgment.

As the JICA team, there is no change in the policy to include the following comments.

- These plans do not have rationale for river engineering. These plans are based on different viewpoints, which JICA Study Team have been emphasizing.
- There is no economic evaluation for the 9 projects
- The order of priorities are incorrect. Prior implementation of Ayutthaya bypass is not a right decision because it increases the risk of flooding in the Bangkok capital where assets and industrial clusters are centered in the downstream.

Therefore, JICA emphasized that the most effective and efficient way for RID is to improve dam management and raise the dike level first as suggested in the MP, and then implement the DC and AB projects at the same time. Besides, JICA asked RID for answers in written form for questions RID did not explain fully on the meeting.

Source : JICA Study Team

Photo 1.4.10 Meeting with RID (November, 2017)

(9) Draft Final Report Meeting

The meeting for the Draft Final Report was held on May 16, 2018. JICA Study Team had explained the results of the study and that the study would take into account the comments from all counterparts. RID commented that RID took responsibility for all area of the Chao Phraya basin, not only downstream of the river. Therefore RID had selected the Ayutthaya Bypass as a precedent project as RID. Regarding the 9 projects proposed by RID, they would be examined by the Office of the National Water Resources (ONWR). JICA Study Team had proposed that the priority of the project implementation should be focused and considered intensively, and the implementation order of the projects including Ayutthaya Bypass should be reconsidered. DOH had mentioned that since the Outer Ring Road project was still under the EIA consideration process, it was possible to readjust the EIA schedule in case RID would continue the next process.

Resource : JICA Study Team

Photo 1.4.11 Draft Final Report Meeting

(10) Seminar on Flood Management of the Chao Phraya River Basin

The seminar on Flood Management of the Chao Phraya River by JICA was held on May 18, 2018. The objective of the seminar was to introduce the outline of JICA MP Study authorized by Thai Government which studied the comprehensive countermeasures against floods in the Chao Phraya river basin after the major flood in 2011. The seminar was also to explain the study result of the Diversion Channel which was proposed as one of the principal projects in the JICA MP Study. The JICA Study Team had attended the seminar and presented the results of study of the Diversion Channel.

Resource : JICA Study Team

Photo 1.4.12 Seminar on Flood Management of the Chao Phraya River Basin

1.4.4 Publicity materials

Three types of publicity materials were made. Three-fold leaflets in Japanese, English, and Thai languages, describing activities and outputs of the study, were distributed together with the invitation letters in the 2nd and 3rd High Level Seminars to public and officers concerned. Seven perspective illustrations presenting the image of the Diversion Channel and the summary pamphlet were prepared as well. The leaflets, perspective illustrations, and summary pamphlet are attached in the Appendix.

CHAPTER2 BASIC PLAN

2.1 Concept of the Outer Ring Road Diversion Channel

2.1.1 Review of the severe flood in 2011

(1) Flood scale

The severe flood in the whole Chao Phraya River Basin in 2011 was the largest flood in the history. According to the rainfall simulation by JICA, the return period of this flood was estimated to be approximately 100 years return period rainfall intensity.

Table 2.1.1 Estimation based on rainfall of the deluge in 2011

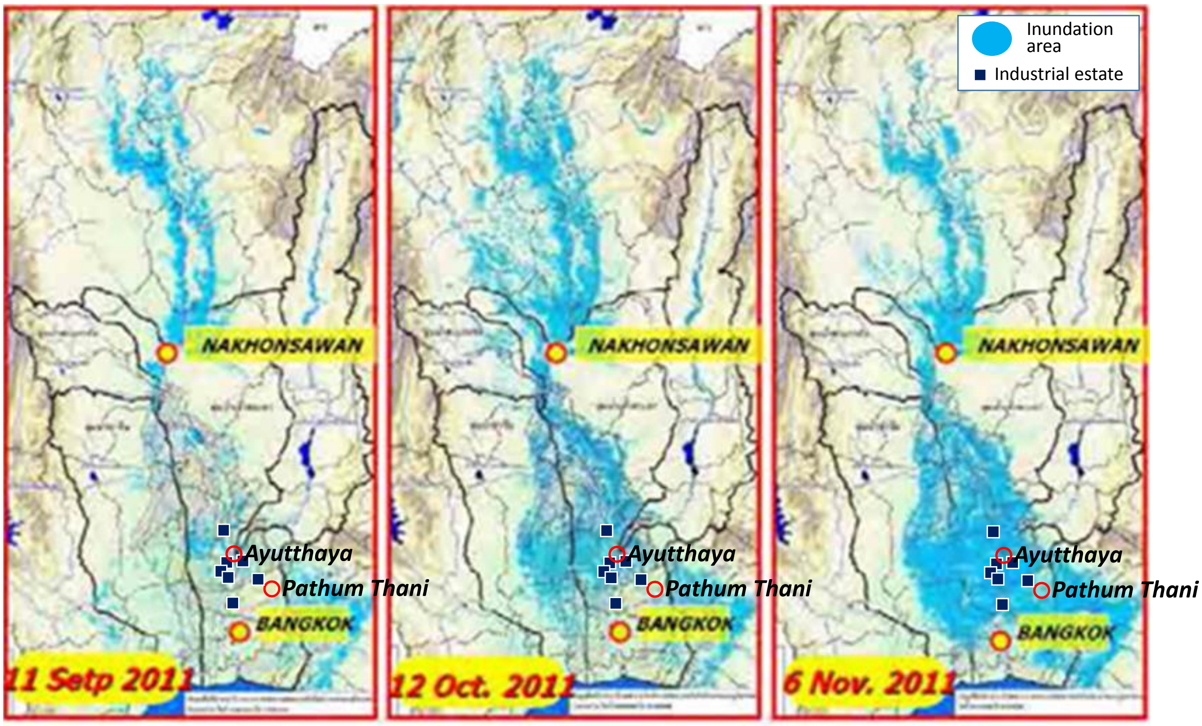
Index for Probability estimation	Upstream Basin of Nakhon Sawan		Entire Chao Phraya River Basin	
	Estimated probable value by the probablity analysis obtaining SLSC of 0.04 or more	Estimated probable value by the probablity analysis obtaining minimum SLSC	Estimated probable value by the probablity analysis obtaining SLSC of 0.04 or more	Estimated probable value by the probablity analysis obtaining minimum SLSC
6 month Rainfall	1/53～1/345	1/141 By Log-normal distribution with 2 parameter method（LN2PM）	1/90～1/207	1/100 By Log-normal distribution with 2 parameter method（LN2PM）

SLSC（Standard Least Squares Criteria）: Probability analysis method obtaining small SLSC has high goodness of fit. Probability analysis method obtaining SLSC of 0.04 or more has goodness of fit.

Source ：JICA Study Team

(2) Inundation situation

The inundation in lower Nakhon Sawan River Basin occurred mainly in mid-September 2011. The inundation was usually caused by dike break and overflow from the river. The inundated water run along the Chao Phraya River causing seven industrial areas being inundated in Ayutthaya, Pathum Thani, and later arrived at Bangkok in early November 2011.



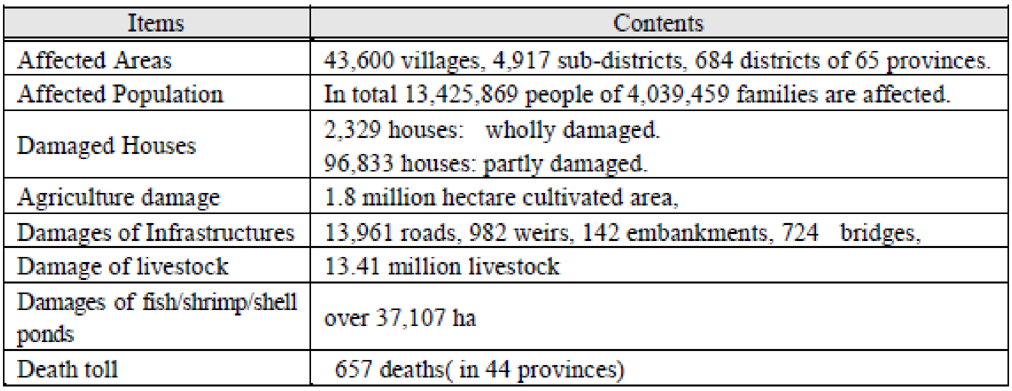
Source ：GISDA

Figure 2.1.1 Inundation area in 2011

(3) Situation of damage

The deluge in 2011 caused enormous damage as shown in Table 2.1.2.

Table 2.1.2 Damage situation in December 1, 2011



Items	Contents
Affected Areas	43,600 villages, 4,917 sub-districts, 684 districts of 65 provinces.
Affected Population	In total 13,425,869 people of 4,039,459 families are affected.
Damaged Houses	2,329 houses: wholly damaged. 96,833 houses: partly damaged.
Agriculture damage	1.8 million hectare cultivated area,
Damages of Infrastructures	13,961 roads, 982 weirs, 142 embankments, 724 bridges,
Damage of livestock	13.41 million livestock
Damages of fish/shrimp/shell ponds	over 37,107 ha
Death toll	657 deaths(in 44 provinces)

Source : DDPM

SCWRM and WFMC carried out an assessment on the effectiveness of several proposed countermeasures including both structures and non-structures. The Outer Ring Road Diversion Channel is one of the effective measures.

2.1.2 Outline of the Authorized Comprehensive Flood Management Plan (JICA MP)

(1) Projects reviewed in the JICA MP Study

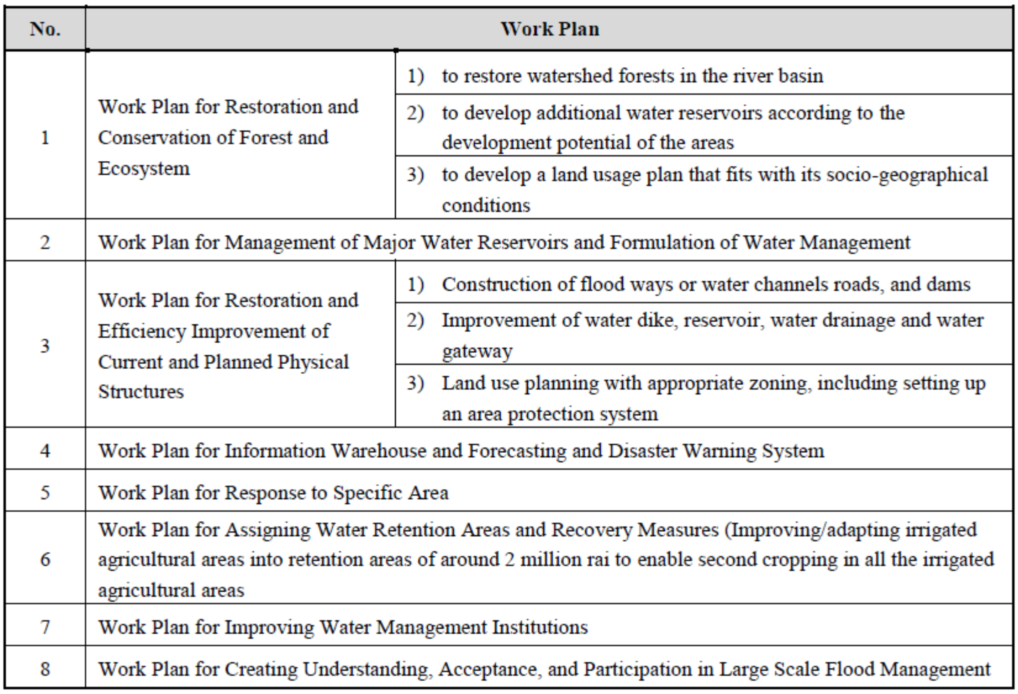
The following projects were reviewed to formulate the JICA MP.

1) Projects stated in the Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011
2) Projects mentioned in Documents of Request for Proposal prepared by WFMC in July 2012
3) Projects newly proposed during the Study

1) The Master Plan formulated by the Strategic Committee for Water Resources Management (SCWRM) in December 2011

In December 2011, the Strategic Committee for Water Resource Management (SCWRM) formulated the Master Plan on Sustainable Water Resource Management composed of both urgent and long term work plans shown in Table 2.1.3, to ensure the continuity of country’s development.

Table 2.1.3 Summary of Master Plan Presented by SCWRM (December 2011)



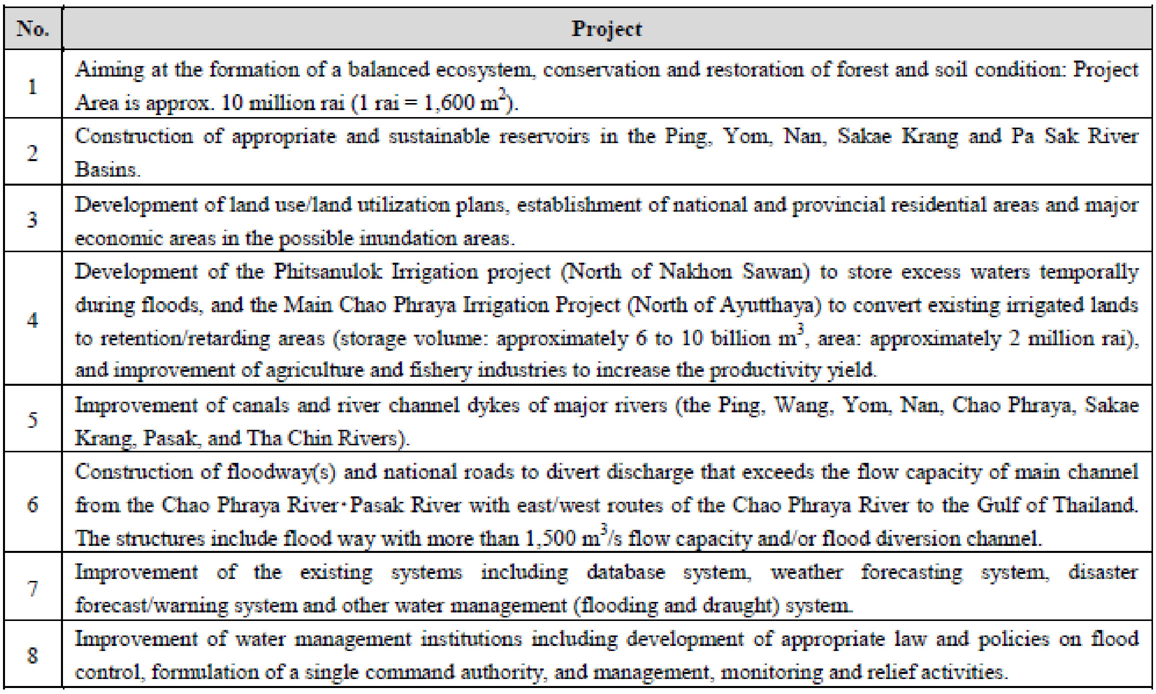
No.	Work Plan	
1	Work Plan for Restoration and Conservation of Forest and Ecosystem	1) to restore watershed forests in the river basin
		2) to develop additional water reservoirs according to the development potential of the areas
		3) to develop a land usage plan that fits with its socio-geographical conditions
2	Work Plan for Management of Major Water Reservoirs and Formulation of Water Management	
3	Work Plan for Restoration and Efficiency Improvement of Current and Planned Physical Structures	1) Construction of flood ways or water channels roads, and dams
		2) Improvement of water dike, reservoir, water drainage and water gateway
		3) Land use planning with appropriate zoning, including setting up an area protection system
4	Work Plan for Information Warehouse and Forecasting and Disaster Warning System	
5	Work Plan for Response to Specific Area	
6	Work Plan for Assigning Water Retention Areas and Recovery Measures (Improving/adapting irrigated agricultural areas into retention areas of around 2 million rai to enable second cropping in all the irrigated agricultural areas	
7	Work Plan for Improving Water Management Institutions	
8	Work Plan for Creating Understanding, Acceptance, and Participation in Large Scale Flood Management	

Source: JICA MP

2) Request for Proposal prepared by WFMC in July 2012 (Full Menu)

In July 2012, the Water and Flood Management Commission (WFMC) announced the Submission of a Conceptual Plan for the Design of Infrastructure for Sustainable Water Resources Management and Flood Prevention, composed of eight projects shown in Table 2.1.4.

Table 2.1.4 Summary of Projects Presented by WFMC (July 2012) (Full Menu)

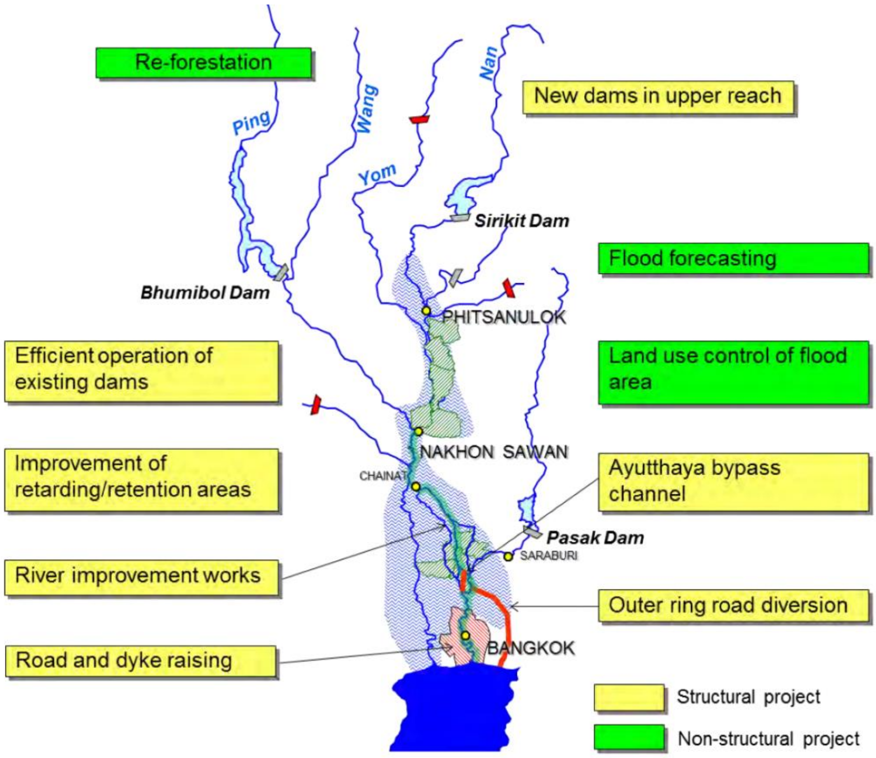


No.	Project
1	Aiming at the formation of a balanced ecosystem, conservation and restoration of forest and soil condition: Project Area is approx. 10 million rai (1 rai = 1,600 m^2).
2	Construction of appropriate and sustainable reservoirs in the Ping, Yom, Nan, Sakae Krang and Pa Sak River Basins.
3	Development of land use/land utilization plans, establishment of national and provincial residential areas and major economic areas in the possible inundation areas.
4	Development of the Phitsanulok Irrigation project (North of Nakhon Sawan) to store excess waters temporally during floods, and the Main Chao Phraya Irrigation Project (North of Ayutthaya) to convert existing irrigated lands to retention/retarding areas (storage volume: approximately 6 to 10 billion m^3, area: approximately 2 million rai), and improvement of agriculture and fishery industries to increase the productivity yield.
5	Improvement of canals and river channel dykes of major rivers (the Ping, Wang, Yom, Nan, Chao Phraya, Sakae Krang, Pasak, and Tha Chin Rivers).
6	Construction of floodway(s) and national roads to divert discharge that exceeds the flow capacity of main channel from the Chao Phraya River･Pasak River with east/west routes of the Chao Phraya River to the Gulf of Thailand. The structures include flood way with more than 1,500 m^3/s flow capacity and/or flood diversion channel.
7	Improvement of the existing systems including database system, weather forecasting system, disaster forecast/warning system and other water management (flooding and draught) system.
8	Improvement of water management institutions including development of appropriate law and policies on flood control, formulation of a single command authority, and management, monitoring and relief activities.

Source: JICA MP

3) Reviewed Projects

For flood risk management purposes, structural and non-structural measures were studied. The reviewed projects are described in the Figure 2.1.2.



Source: JICA MP

Figure 2.1.2 Projects Reviewed in the JICA MP Study

(2) Design Flood

The 2011 Flood, the largest recorded flood, caused tremendous damage in the whole Chao Phraya River Basin. The 2011 Flood has been estimated as a 100-year return period flood in the rainfall analysis executed in JICA MP Study. Most metropolitan cities in the Asian monsoon region have similar target scales more than 100-year return period to prevent flood damages. From the above considerations, it is appropriate to set the 2011 Flood (the 100-year return period) as the design flood for the Chao Phraya River Basin.

(3) Protection Area

Since Bangkok and its vicinity (the east side of the Tha Chin River and the south part of the Pa Sak River in Ayutthaya) were selected as the flood protection area, the same area was selected as the prioritized flood protection area in the JICA MP Study.

(4) Combination of Countermeasures

More than ten (10) scenarios have been simulated after developing of a new basin-wide hydrological model incorporating a new topographical map. It has been concluded that the Ayutthaya Bypass Channel and the Outer Ring Road Diversion Channel in combination with other structural and nonstructural measures, such as efficient operation of existing dams and river channel improvement works, are the most cost-efficient and significantly effective to protect the lower Chao Phraya River basin.

Proposed Combination 1

1) Effective operation of existing dams
2) Outer Ring Road Diversion Channel (Capacity: 500 m^3/s)
3) River improvement works (including the Tha Chin River improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400 m^3/s)
5) Flood forecasting

Proposed Combination 2

1) Effective operation of existing dams
2) Outer Ring Road Diversion Channel (Capacity: 1,000 m^3/s)
3) River improvement works (including Tha Chin River improvement)
4) Ayutthaya Bypass Channel (Capacity: 1,400 m^3/s)
5) Flood forecasting

(5) Project evaluation for design flood

Three kinds of project combination, such as above two combinations proposed by the JICA MP Study and full menu proposed by Thai Government, were evaluated for the design flood. Table 2.1.5 shows the project costs and result of economical evaluation.

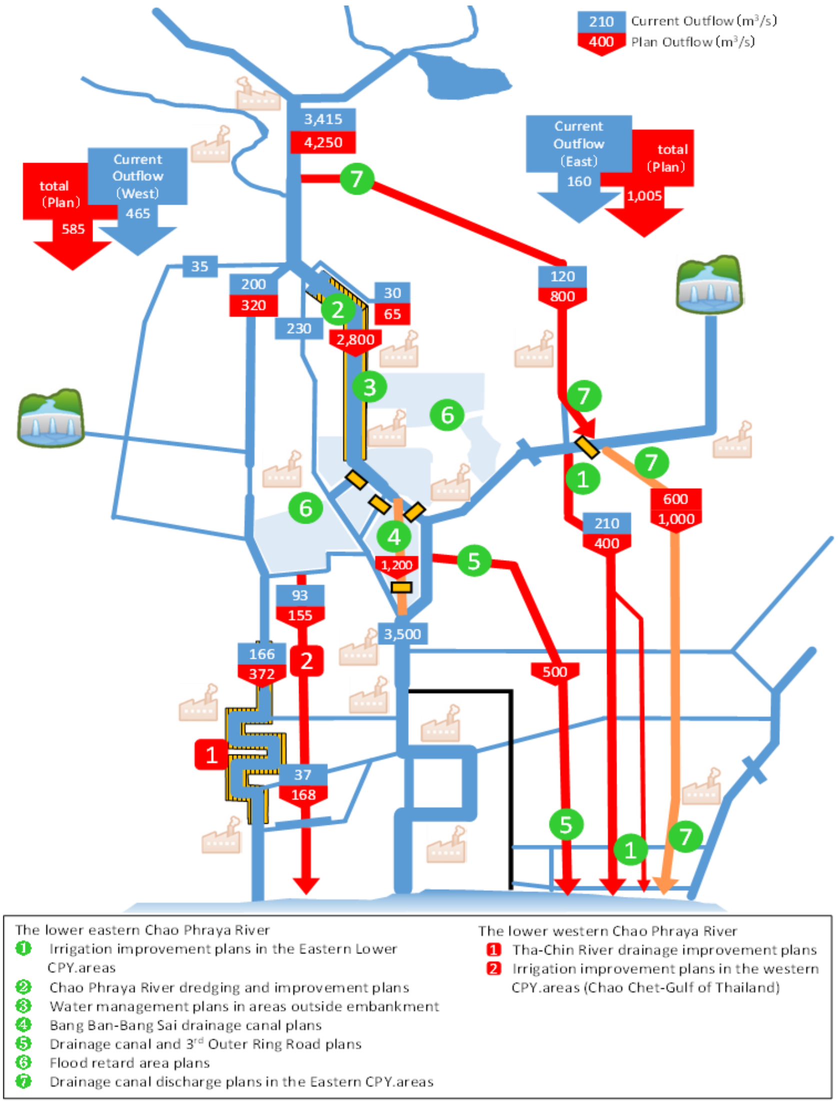
Table 2.1.5 Project costs and result of economical evaluation

	Project Cost (Billion Baht)	EIRR	Benefit / Cost	Net Present Value (Billion Baht)
Full Menu	508	13%	1.1	21
Proposed Combination 1	143	29%	2.7	137
Proposed Combination 2	190	25%	2.2	127

Source: JICA MP

2.1.3 Necessity of the Outer Ring Road Diversion Channel

The effects of flood damages reduction by JICA MP versus those of the RID Plan were conducted, requested by RID on February 2017. RID Plan is shown in Figure 2.1.5. The plan proposed drainage canal discharge in the Eastern Chao Phraya areas and Irrigation improvement in the Eastern Lower Chao Phraya areas in addition to construction of Ayutthaya bypass Channel and the Outer Ring Road Diversion Channel.



Source: RID Document in February 2017

Figure 2.1.3 The flood disaster mitigation plan by RID
(The flood disaster mitigation plan in the downstream of the Chao Phraya River Basin by RID)

Effectiveness of JICA MP and RID plan has been compared. For JICA MP, the plan consists of the construction of Ayutthaya Bypass and the Outer Ring Road Diversion Channel. For RID plan, the plan consists of the construction of Ayutthaya Bypass, the Outer Ring Road Diversion Channel, the Expansion of Chai Nat Pasak, and the Eastern Diversion Channel. The design flood in JICA MP is assumed as the target flood. For both JICA MP and RID plans, flow capacity of Ayutthaya Bypass is assumed to be 1,200 m^3/s in accordance with the Feasibility Study conducted by RID.

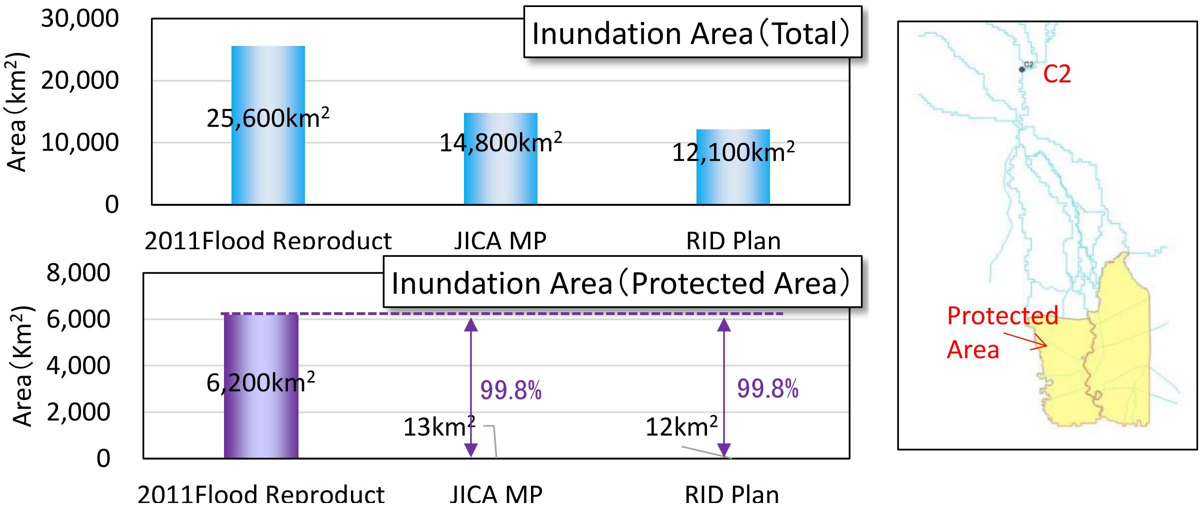
Table 2.1.6 Flow capacity in the calculation

unit : m^3/s

	Ayutthaya Bypass	Outer Ring Road Diversion Channel	Chai Nat・Pasak Channel	Raphiphat Channel	Eastern Diversion Channel
JICA MP	1,200	500	210（current）	210（current）	（none）
RID Plan	1,200	500	800	400	800

Source：JICA Study Team

Calculation result is shown as follows.



Source ：JICA Study Team

Figure 2.1.4 Comparison of the flood mitigation measures

For the severe flood in 2011, inundated area simulation results from JICA MP and RID Plan are compared, and the results are shown in the Figure 2.1.4. The results are apparently close, especially in terms of the protected area. Thus, JICA MP's mitigation measures shall be considered as the effective measure in flood management. Furthermore, JICA MP shall be considered as a priority project due to its effectiveness for flood management, while other menu in RID Plan those were irrigation improvement projects shall be considered together or after that. The evaluation of the effectiveness of RID plan (October 2017) is shown in Chapter 4.

2.2 Basic Policy

2.2.1 Benefits of the project integration

The alignment of the Diversion Channel was planned to be situated adjacent alongside the Outer Ring Road (East section). DOH had already completed the Feasibility Study of the Outer Ring Road, the alignment from the study is shown in Figure 2.2.1.

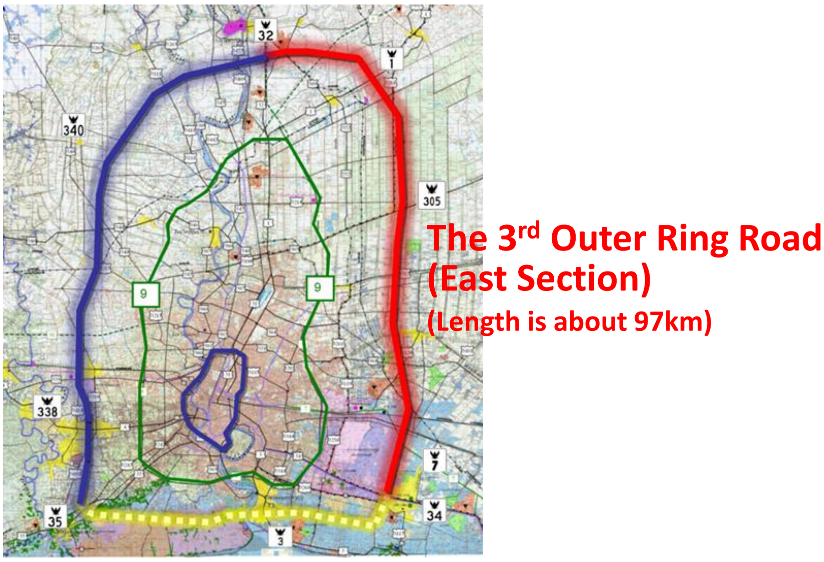


Figure 2.2.1 The 3rd Outer Ring Road

JICA is expecting merits from the project integration as follows.

- In terms of social impact, the areas trapped between the two projects may be isolated, leading to a great decrease in the land value. This problem can be avoided by integration of the two projects.
- In terms of economy, the construction cost can be reduced by utilizing excavated soil from the Diversion Channel for construction of the embankment of the Outer Ring Road.
- In terms of Time, integration of the two projects can accelerate the implementation of the projects.

The utilization of excavated soil for construction of road embankment is common in Japan.

When construct the two projects integrated, the total width of the required space will be approximately 206 to 251 meters, being 166 meters for the Diversion Channel and 70 to 85 meters for the embankment in the section of the Outer Ring Road (East section) while 40 meters for the section of elevated road structure. The length of the Diversion Channel being adjacent alongside with the Outer Ring Road is approximately 45km, equals to 46% of the total length of the Outer Ring Road that is approximately 97km.

< Length of the section, where the Diversion Channel is adjacent to the Outer Ring Road >

From km. 22.500 to km. 52.500 = 30.000km
From km. 82.000 to km. 97.112 = 15.112km
Total: 45.112km

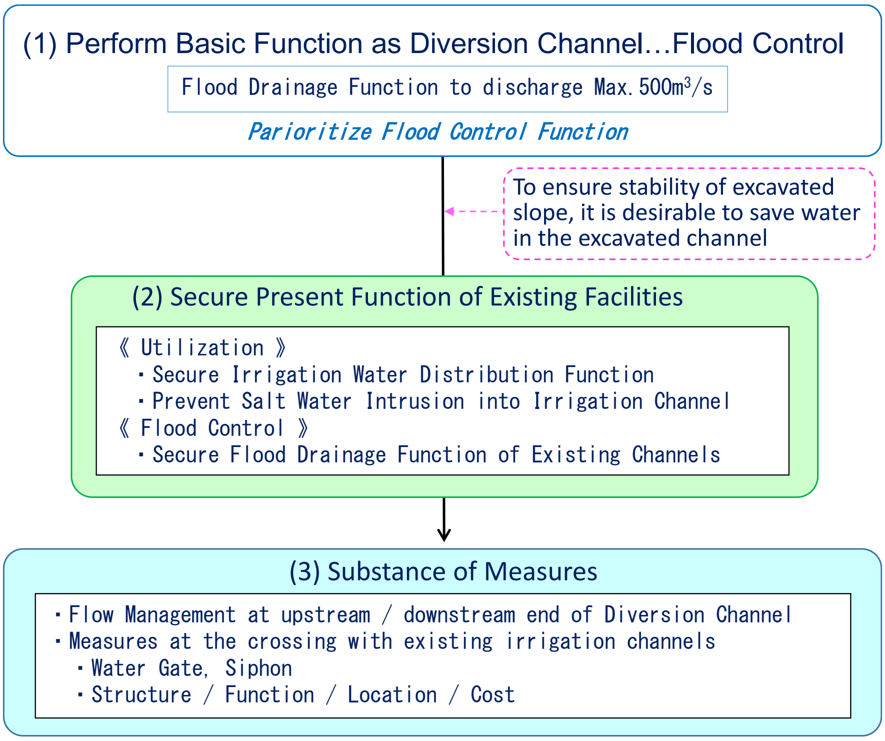
< Ratio of the adjacent length to the total length of the Outer Ring Road (East Section) >

1) Length of the Outer Ring Road (East Section): 97.112km
2) Length of the section, where the Diversion Channel is adjacent to the Outer Road: 45.112km
1)／2)＝46％

Rangsit Channel was constructed during the era of King Rama V. It is one of the examples, and a good reference, with this advanced section design. Especially, there is a vegetation area between the Rangsit Channel and road, providing an area for common uses. The service road will be constructed at the east side of the Diversion Channel, considering convenience for local people and proposing reduction of the land acquisition at the same time.

2.2.2 Usage of the Diversion Channel

The Diversion Channel is a facility which its primary purpose is for flood control. Therefore, flood control function is a top priority. The function of the existing irrigation canal network must be maintained, thus the construction of the Diversion Channel shall not divide the existing irrigation channels. An additional hydraulic function can be added after satisfying the above functions.



(1) Perform Basic Function as Diversion Channel…Flood Control

Flood Drainage Function to discharge Max. 500m^3/s

Parioritize Flood Control Function

To ensure stability of excavated slope, it is desirable to save water in the excavated channel

(2) Secure Present Function of Existing Facilities

《 Utilization 》
- Secure Irrigation Water Distribution Function
- Prevent Salt Water Intrusion into Irrigation Channel

《 Flood Control 》
- Secure Flood Drainage Function of Existing Channels

(3) Substance of Measures

- Flow Management at upstream / downstream end of Diversion Channel
- Measures at the crossing with existing irrigation channels
  - Water Gate, Siphon
  - Structure / Function / Location / Cost

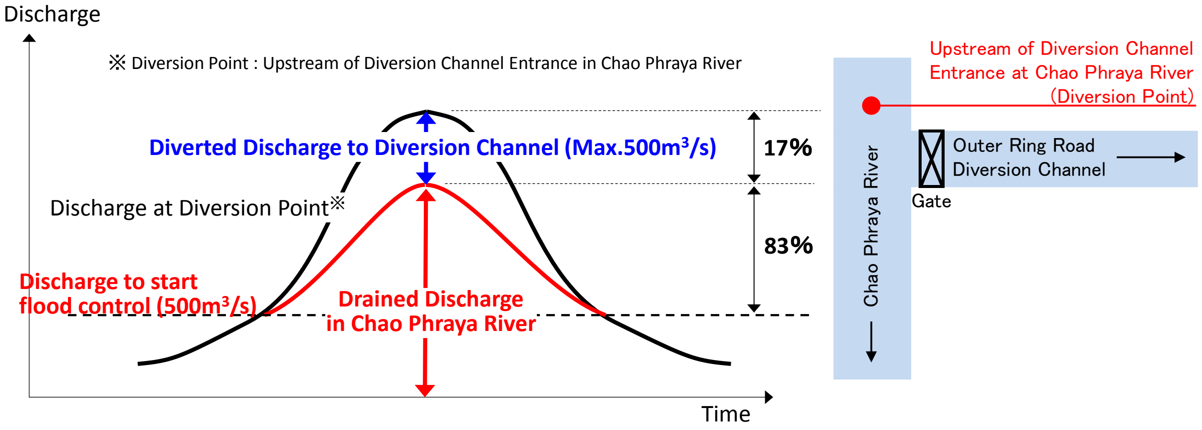
Source : JICA Study Team

Figure 2.2.2 Concept of Diversion Channel operation

(1) Operation for flood control

The concept of the Outer Ring Road Diversion Channel for flood control is described as follows:

In case of discharge at the upstream of the Diversion Channel Entrance at the Chao Phraya River (Inflow Point) exceeds 500m^3/s, flood diversion to the Channel will start. Discharge volume of 17% of the inflow exceeding 500 m^3/s at the Inflow Point will be diverted to the Diversion Channel, as shown in Figure 2.2.3. The return period of the discharge exceeding 500 m^3/s at the Inflow Point is once every three years. (Refer to Supporting report “1.5 Methodology of diverting the flow of the river into the Outer Ring Road Diversion Channel”.) Discharge volume that will be diverted to the Diversion Channel is 17% of the water flow exceeding 500m^3/s at the Inflow Point. (Refer to Figure 2.2.3) From the above, the Diversion Channel will be used even during small and medium floods, and it is possible to avoid the situation that the Diversion Channel is not used despite the flooding along the main river.



Source : JICA Study Team

Figure 2.2.3 Flood control method

It is desirable that the flow rate and inflow frequency to the Diversion Channel during flooding can be variably adjusted. There are a fixed weir type and a gate type for diversion method. The fixed weir type is inexpensive, but the flood frequency and the partial flow rate are fixed. Therefore, the gate type that can flexibly adjust the flow rate is adopted.

Table 2.2.1 Comparison of the structure at the entrance of Diversion Channel

	Fixed weir type	Gate type
Advantage	- Only fixed weir is necessary, so it is inexpensive - Operation is not necessary	- Control is possible - It is possible to adjust the inflow frequency to the Diversion Channel - It is possible to minimize the width of channel at the entrance part
Disadvantage	- Extension of the overflow section is long, so the land cost is large - If excessive flood occurs, there is a danger that discharge exceeding design discharge will flow down	- Expensive because gate is necessary - Operation rule is necessary
Image	 reinforced concrete	

Source : JICA Study Team

From Honma's overflow formula[1], the width that the overflow of 500 m^3/s can pass, against the 2011 flood, is approximately 50 m. This calculated width is shorter than that of the Diversion Channel, 120 m. Therefore, the width of the gate may be set to the width of the channel.

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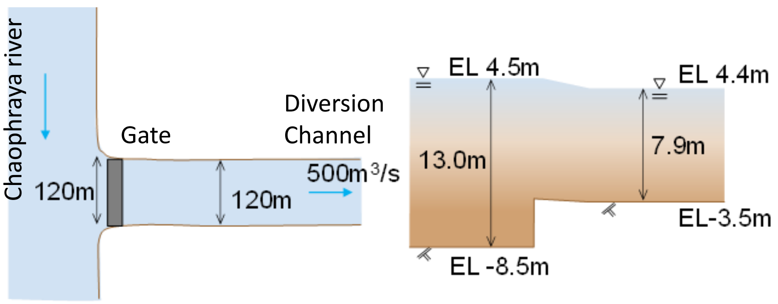
[1] The Collection of Hydraulic Formulae (Japan Society of Civil Engineers 1999)



【Plane figure】　　【Cross section】

Source : JICA Study Team

Figure 2.2.4　Overflow calculation for the gate type

1) Calculation method of overflow

The Honma's front overflow formula is used for the calculation of overflow discharge. The direction of the overflow is nearly the same as the cross section of the diversion channel. As the riverbed slope is about 1/50,000, therefore, the Q_S component of the overflow discharge can be neglected in the Kuriki's formula[2].

i. Honma's front overflow formula is as follows;

Free overflow condition（$h_2/h_1 < 2/3$）: $Q_0 = 0.35Bh_1\sqrt{2gh_1}$

Submerged overflow condition（$h_2/h_1 \geqq 2/3$）$Q_0 = 0.91Bh_2\sqrt{2g(h_1 - h_2)}$

where, h_1 and h_2 are the Chao Phraya river and diversion channel depths from weir height, respectively ($h_1 > h_2$). *B* is the width of diversion channel.

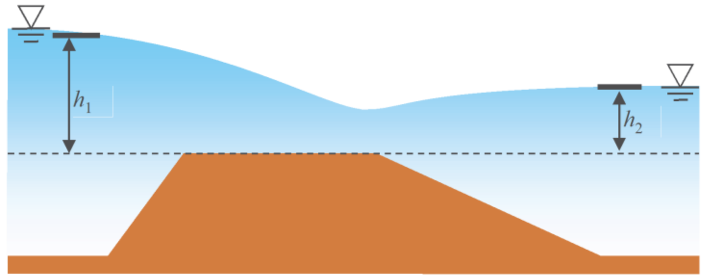
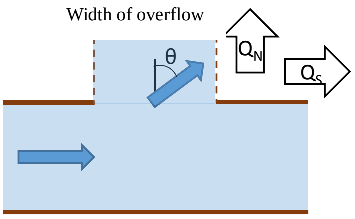


Figure 2.2.5　The image of the overflow formula

ii. Kuriki's Lateral overflow formula is as follows;



$$Q_N = \alpha Q_0 \cos\theta \qquad Q_S = \alpha Q_0 \sin\theta$$

Where Q_N, Q_S are the lateral overflow discharge of the normal and tangential direction, respectively. Q_0 is the front overflow discharge calculated by Honma's formula.

α is the correction coefficient as follows;

- $I >$ 1/1,580 condition : $\alpha = 0.14 + 0.19\log_{10}(1/I), \theta = 48 - 15\log_{10}(1/I)$
- 1/1,580 $\geqq I >$ 1/33,600 condition : $\alpha = 0.14 + 0.19\log_{10}(1/I), \theta = 0$
- 1/33,600 $\geqq I$ condition : $\alpha = 1, \theta = 0$

Where *I* is the riverbed gradient, and θ is the angle.

---

[2] The manual of Creating flood inundation assumption area maps

2) Calculation result of the overflow

From the above considerations, the width of the diversion channel is between 50 meters and 120 meters under the discharge condition of 500 m^3/s in the diversion channel.

From the calculation results, the gate width of the diversion channel can be set to 50 meters. However, the gate width of the diversion channel is set to120 meters to enable flexible water uses.

Table 2.2.2 The overflow discharges results

Condition	Item	Submerged overflow	Remarks
Front overflow	Water elevation (Chao Phraya river: H_1)	4.50	DHWL of the Chao Phraya River
	Water elevation (diversion channel: H_2)	4.40	Numerical water elevation
	Riverbed height (diversion channel: Z)	-3.50	
	Overflow weir height （H）	-3.45	
	ΔH(=H-Z)	0.05	for convenience
	Water depth (Chao Phraya river:h_1)	7.95	
	Water depth (diversion channel:h_2)	7.85	
	h_2/h_1	0.99	$h_2/h_1 \geqq 2/3$ for the submerged overflow condition
	Width of diversion channel (B)	50	
	Gravitational acceleration (G)	9.8	
	Discharge of the front overflow (Q_0)	500.04	submerged overflow condition
Lateral overflow	Angle of the inflow	0	1/33,600≧ I(1/50,000)
	Correction coefficient	1	
	Discharge of the lateral overflow (Q)	500.04	

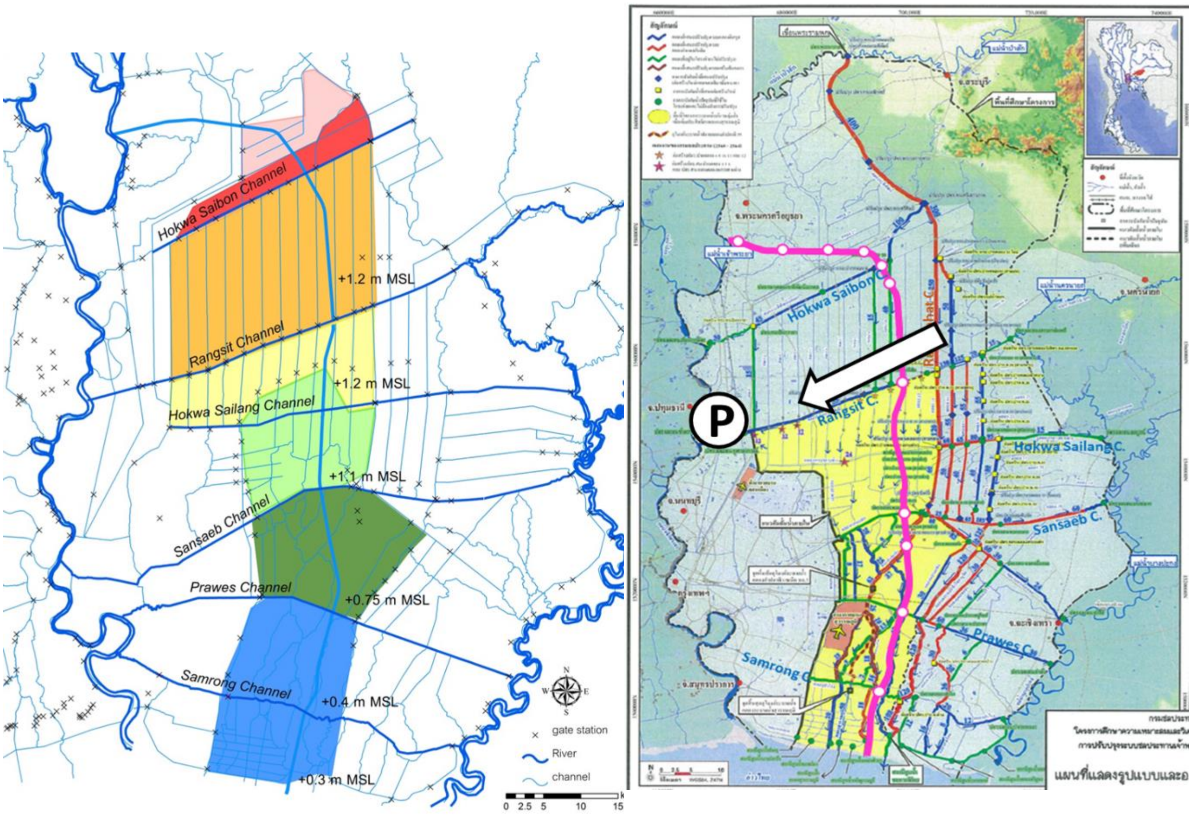
(2) Maintaining the existing functions of other facilities (use during non-flood period)

1) Function of water utilization

As shown in the Figure 2.2.6, the paddy field along the Diversion Channel is divided into seven irrigation areas. The target water level to be maintained in each irrigation area is set. The water gate installed at the intersection of each waterway is operated in order to maintain the target water level. After the completion of the Diversion Channel, it is required to maintain these existing irrigation functions. In addition, in the downstream area, salt water may rise from the bottom of the irrigation channel during drought. For this reason, measures should be taken to prevent salt water intrusion into the Diversion Channel.

2) Function of flood control

As shown in the Figure 2.2.6, in the RID plan, the design drainage discharge is allocated to the channel network divided from the Raphiphat Channel. Currently, drainage capacity of undeveloped channel has not reached design capacity. For this reason, after grasping the drainage capacity of each channel, it is necessary to perform flood drainage corresponding to the drainage capacity of the pump installed at the end of the channel network during flooding. After the completion of the Diversion Channel, it is required to maintain the drainage capacity of the existing channel network.



Source : JICA Study Team, based on data from RID

Figure 2.2.6 Seven irrigation areas (left) and drainage plan (right)

(3) Countermeasures

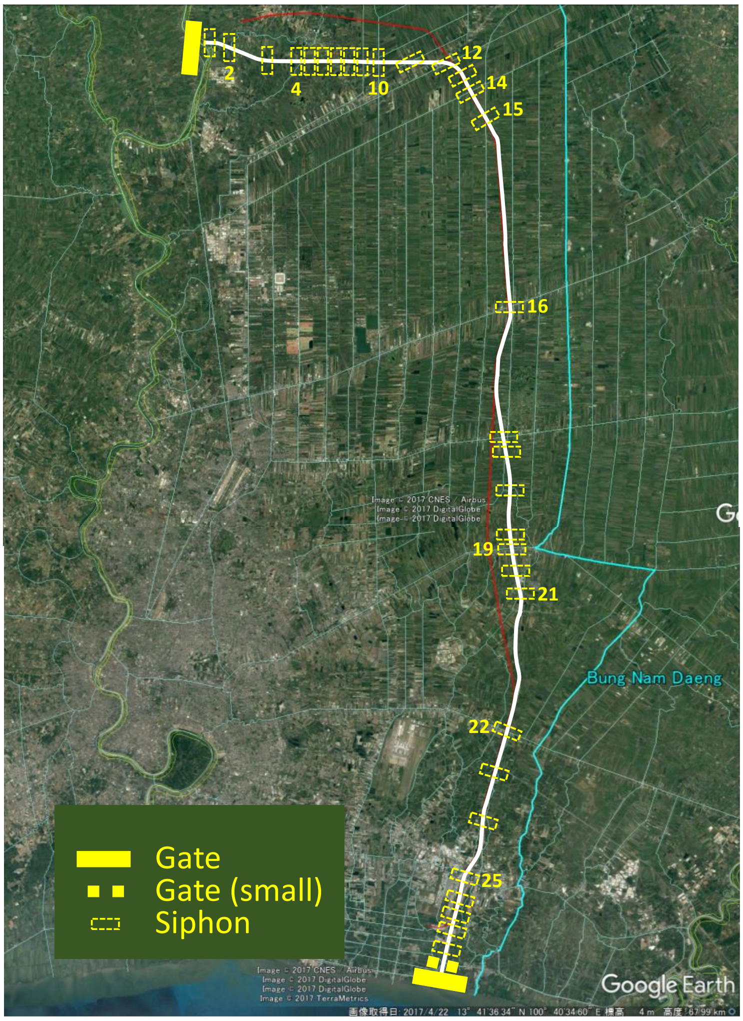
1) Facility for flood control

At the entrance of the Diversion Channel, sluice gates are constructed in order to control inflow to the channel at the flooding time.

2) Facilities for maintaining functions of existing irrigation channels

The siphon system for 31 crossing irrigation channels are constructed in order to secure the function of existing irrigation channel. At the end of Diversion Channel, sluice gates are constructed in order to protect the salt water intrusion.

The basic design of these structures is described in section 2.4.



Source : JICA Study Team

Figure 2.2.7 Location of gates and siphon

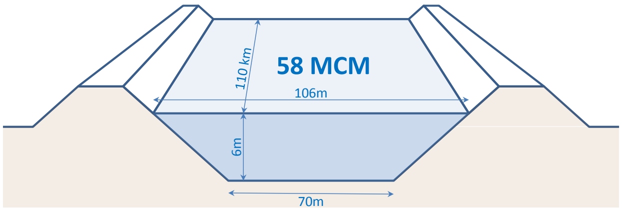
(4) Maintaining the existing functions

1) Maintaining the irrigation function during non-flooding period

Where the Diversion Channel intersects the existing irrigation channels, it is necessary to preserve the irrigation water allocation function of the existing irrigation channels during non-flooding period. For this reason, siphons (overhang passing through the lower part of the Diversion Channel) will be installed at the intersection so as to enable distribution of irrigation water crossing the Diversion Channel.

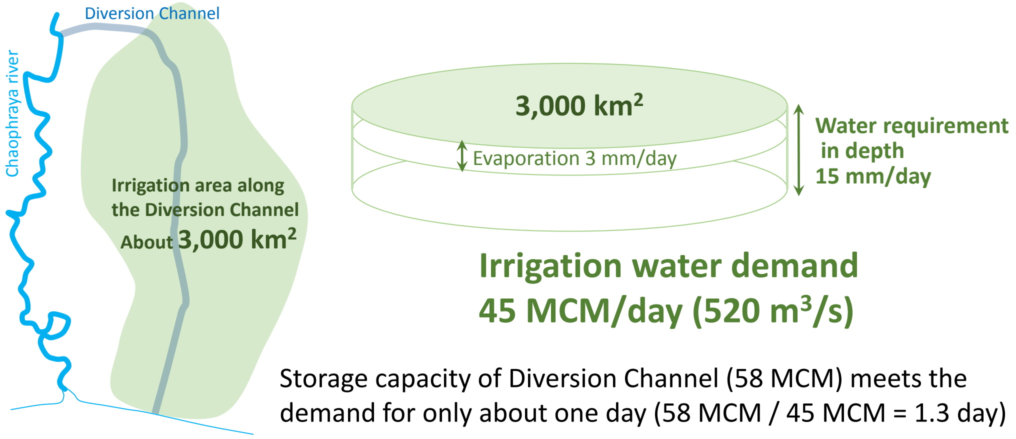
2) Possibility of irrigation water storage

The use as irrigation water storage facility is proposed, as a way of utilizing the Diversion Channel during non-flooding period. However, although the storage capacity of the Diversion Channel below the current ground level is about 58 MCM, it is a small amount compared with the effective storage capacity of 9,662 MCM of the Bhumibol Dam and the effective storage capacity of 6,660 MCM of the Sirikit Dam. Assuming that the area of paddy field along the diversion channel is 3,000 km^2 and the amount of water consumption in the paddy field considering the evapotranspiration is 15 mm/day, the water demand for the dry season is 45 MCM/day. The storage amount of 58 MCM can be supplied approximately for only 1.3 days for the demand of the paddy field.



Source : JICA Study Team

Figure 2.2.8 Amount of storage in the diversion channel below the current ground level



Storage capacity of Diversion Channel (58 MCM) meets the demand for only about one day (58 MCM / 45 MCM = 1.3 day)

Source : JICA Study Team

Figure 2.2.9 Storage capacity of the Diversion Channel

2.2.3 Perspective on road design

(1) Project background

The Outer Ring Road was planned by the DOH, as the toll road, after the completion of the 1st and 2nd Outer Ring Roads, in order to solve the problem of traffic congestion in the capital city. The location of the Outer Ring Road is outside of the 2nd Outer Ring Road and the design speed is 120 km/hour. The route is divided into three sections, namely East section, West section and South section. The total length of the route is 254 km. The integration of the Diversion Channel with a 97 km-long segment of the Outer Ring Road (East section) is supposed as a pre-condition of this project. The Feasibility Study of the Outer Ring Road was conducted during October 2006 to December 2007.

(2) Discussion in the view point of project integration

From the Outer Ring Road Feasibility Study Report (DOH, August 2009), the following items shall be reconsidered.

1) Control of residual settlement

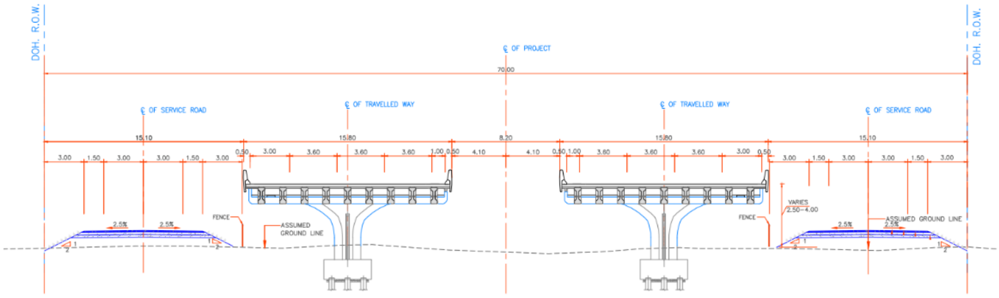
Regarding the four alternatives for controlling the residual settlement stated in DOH FS section 4, the evaluation criteria shall be revised in accordance with this study, with the aforementioned references, in the view point of the "Integrated Project" of the Outer Ring Road and the Diversion Channel. Pile Embankment method was considered suitable in the DOH FS, while Pre-loading with PVD method was selected as the most suitable method in this study.

2) Viaduct in East Section

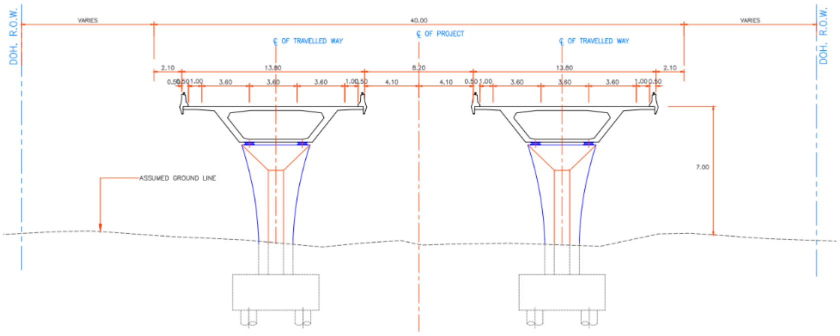
The soft ground condition around IC-11 is deepest among the east section of the Outer Ring Road. Therefore, it is necessary to study not only the methods mentioned above, but also a viaduct structure. Although the construction cost of viaduct will be higher than the cost of embankment structure with the methods shown in Table 2.2.3, the viaduct structure will be reasonable with the following conditions.

i. when the method of "Preloading + PVD" requires duration time for consolidation longer than the construction period set in DOH FS (4 years), conse
ii. quently the project evaluation becomes economically "not feasible" due to increased loss of earnings caused by the delay.
iii. when the method of "Pile Embankment" or "Soil Cement Column" is selected for controlling residual settlement, but then the pile length is not sufficient (shorter than the soft ground layer thickness), consequently it shall be concerned by the differential settlement and increasing maintenance cost.
iv. even though when the above-mentioned conditions are not a point of concern, the land acquisition (100 meters with service roads or 70 meters without service roads) seems to be rather a difficult task due to the progressive urbanization around IC-11.

The typical cross sections for the viaduct (6 lanes) are shown in Figure 2.2.10. It can be seen that, the right of way (R.O.W) for the viaduct becomes narrower, 70 meters with service roads or 40 meters without service roads, than those when using embankment road.



TYPICAL SECTION ②
MAIN ROAD AND SERVICE ROAD TYPICAL SECTION
STA. 88+800 TO STA. 95+600 EAST LINE



TYPICAL SECTION ③
STA.96+560 – STA.97+112

Source：JICA Study Team based on DOH FS 2009

Figure 2.2.10　Typical cross section of viaduct for the Outer Ring Road (6 lanes)

3)　Utilization of excavated soil from the Diversion Channel

Tentative mix ratio of excavated soil, purchased sand and quick lime in order to use the excavated soil as a subgrade and the embankment of the road is shown in the table below.

Table 2.2.3　Tentative mixing specifications for utilization of excavated soil for road structure

	Road design specification example	Formulation example (proposed this time)
Lower Subbase Sub Base course	CBR≧25% t=15 cm	CBR≧25% Unconfined compression strength≧0.75 MPa (In the case of lime mixing)
Subgrade Compacted Subgrade	CBR≧ 4% t=100 cm	・of the subgrade, the upper 30 cm (capping layer): Set to be CBR > 15 ・of the subgrade, the lower 70 cm Set to be CBR > 4% Estimated formulation（Tentative) Excavated soil (clay)：Purchased soil (sand)＝2 : 1 Quicklime (weight ratio) about 5% (if necessary)
Embankment	CBR≧ 4% t=145 cm	q_c＞400 kN/m^2 Estimated formulation（Tentative) Excavated soil (clay)：Purchased soil (sand)＝2 : 1

Source：JICA Study Team

Basically, utilization of excavated soil is expected to reduce the disposal of excavated soil and treatment costs. On the other hand, when use the excavated soil as embankment, it can be expected to reduce the purchase and transportation costs of embankment soil and reduce waste disposal cost of excavated soil. However, in this case, the soil excavated on site cannot be used for embankment as it is, but shall be used as a mixture material (mixed with sand, lime, cement, etc.). Therefore, the benefits is reduced by "cost required for mixing", but the benefit is still mainly a "reduction of disposal cost of waste disposal".

The table below shows the comparison of road construction cost between no-mixing case (embankment constructed with purchased soil, DOH FS) and mixing case (combined structure of the Outer Ring Road and Diversion Channel, JICA Study Team's proposal).

Table 2.2.4 Comparison of road embankment and subgrade cost item (with and without mixing)

Item	DOH FS (2009) without Mixing	Combined Structure with Mixing	Remarks
Utilization of Excavated Soil	None	Yes	
1) Purchasing cost for soil	Cost of selected soil is assumed at 119 THB/m^3	Cost of sand is assumed at 135 TBH/m/^{3}. The amount of sand will be 1/3 of the amount of the total material (in the case of clay : sand ratio = 2:1) . Consequently, the cost of purchase material will be 1/3 of selected soil specified in DOH FS.	The quantity of the materials will be fixed based on the result of mixing test.
2) Transportation, grading and compaction cost	Location of borrow pit for selected soil is assumed in Saraburi Province. The distance for transportation will be 69.5 km (average)	Location of borrow pit for sand is assumed in Ang Thong Province. Even if the distance of transportation is same as selected soil, the cost of transportation will be 1/3 because the less amount than that of selected soil (1/3 at the case of clay : sand ratio = 2:1) .	Low cost mountain sand will be acceptable.
3) Soft ground treatment cost	The cost of Pile Embankment will be 2,664 BHT/m^2 (No excavated soil to be utilized for embankment) in 2017 price and including Soil Cement Slab cost.	The cost of PVD will be 1,320 BHT/m^2 The cost of stockpile for material (this stockpile is used as preloading) shall be included in the mixing cost.	It shall be noted that the settlement of precipitated consolidation by PVD and preloading causes additional embankment volume.
4) Mixing cost	0	Mixing cost includes followings. • Creation of stockpile • Transportation to mixing plant • Operation of mixing plant (includes assemble and dismantle of the plant, depreciation cost of plant) • Cost of additives (lime or cement)	
5) Disposal cost	0	Disposal cost for excavated soil from diversion channel can be saved.	

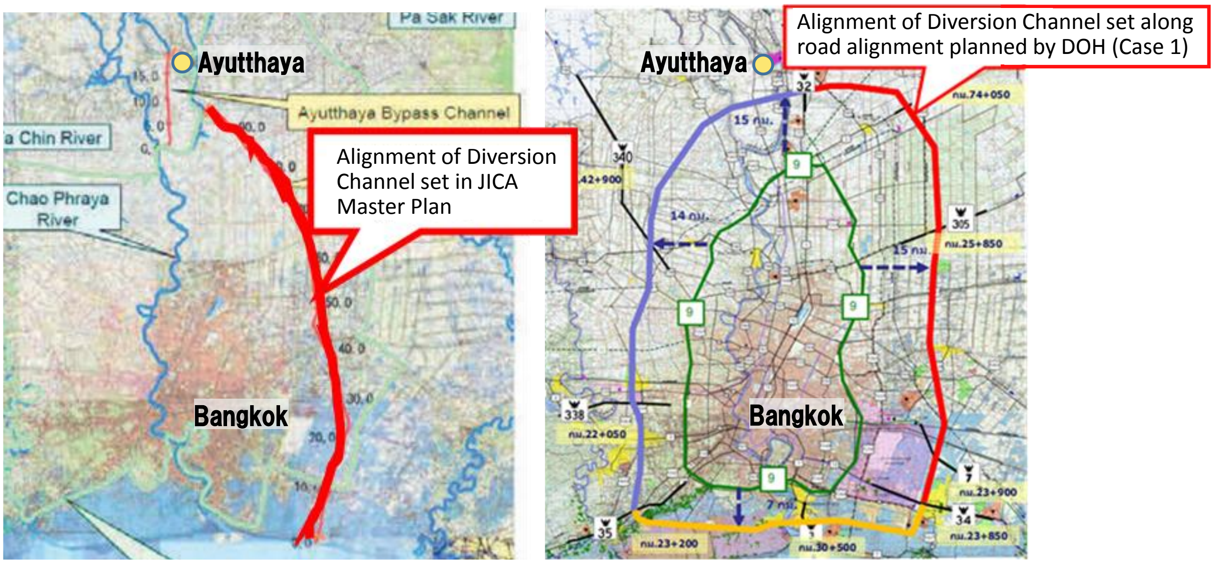
Source : JICA Study Team

2.3 Basic Factors

(1) Specifications of the Diversion Channel（Flow rate, Section and Longitudinal design）

1) Resetting of the alignment set in the JICA Master Plan

The alignment set in JICA Master Plan is different from the alignment of the 3rd Outer Ring Road set by DOH, therefore, the alignment of the channel was reset so as to go along with the alignment of the road. As a result of resetting, the length of the channel became 114.2km that is longer than the length of 98.4km in JICA Master Plan. In this study, the alignment of the Diversion Channel has been improved from this initial alignment (Case 1 as described later) considering some conditions along the channel. And based on this improved alignment, longitudinal and cross section profile has been determined.



Alignment of Diversion Channel set in JICA Master Plan

Alignment of Diversion Channel set along road alignment planned by DOH (Case 1)

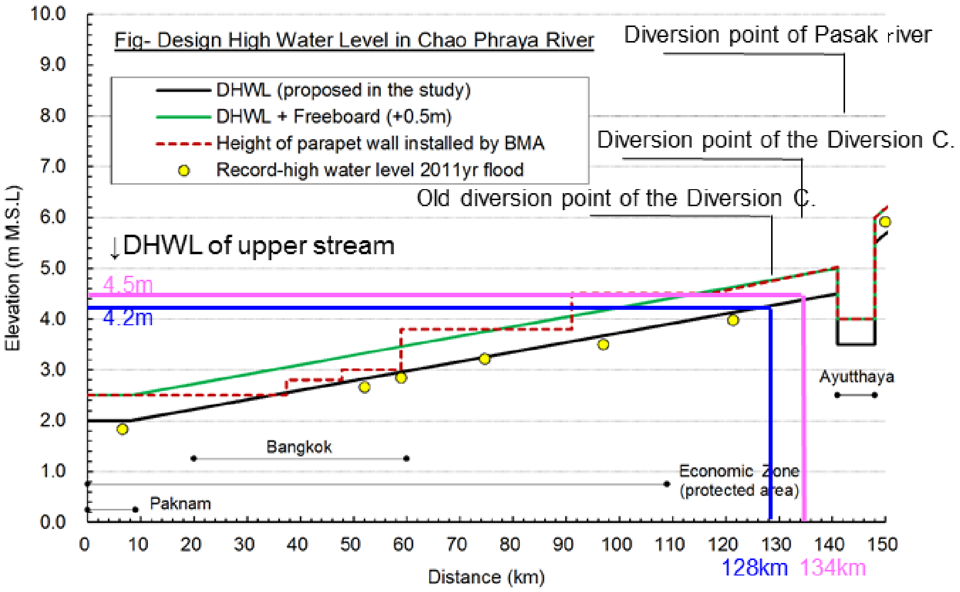
Source：JICA Study Team

Figure 2.3.1 Alignment in JICA Master Plan and alignment along the Outer Ring Road

Table 2.3.1 Reset Profile of the Diversion Channel

	Alignment of Diversion Channel set in JICA Master Plan	Alignment of Diversion Channel set along road alignment planned by DOH (Case 1)
Length of Diversion Channel	98.4 km	114.2 km
Design High Water Level at the upstream end of Diversion Channel	4.2 m	4.5 m

Source：JICA Study Team



Source : JICA Study Team

Figure 2.3.2 Design High Water Level (DHWL) of the Chao Phraya River

(2) Alignment of Diversion Channel

1) Preconditions

The Outer Ring Road (East section) is 97 km-long running through Ayuttaya Province, Pathum-Thani Province, and connects with The Outer Ring Road (South section). The Outer Ring Road (East section) is located about 15 km outside The 2nd Outer Ring Road. The Outer Ring Road Diversion Channel is planned along with the Outer Ring Road (East section), from Ayuttaya until the Gulf of Thailand with a total distance of 110 km. JICA designs the alignment with full attention and respect to DOH's plan of the Outer Ring Road (East section). The FS of the Outer Ring Road (East section) has been finished in August 2009. The road width is 100 meters with three main lanes (70 meters) and two service roads on both sides (15 meters each). The pre-conditions of the alignment design for the Diversion Channel is assumed as follows.

The function of the Diversion Channel

- As the most cost-effective water management, the Diversion Channel can control the inundated area in the Chao Phraya Basin and protect the economic center located in the lower basin against flooding.
- Water the Chao Phraya River will be diverted into the Diversion Channel and runs to the Gulf of Thailand through the eastern basin.

Environmental and Social Impact

- Consideration shall be to avoid sensitive and immovable facilities (temple, mosque, hospital, school, etc.)
- Consideration shall be to minimize number of relocation (house, factory, etc.)

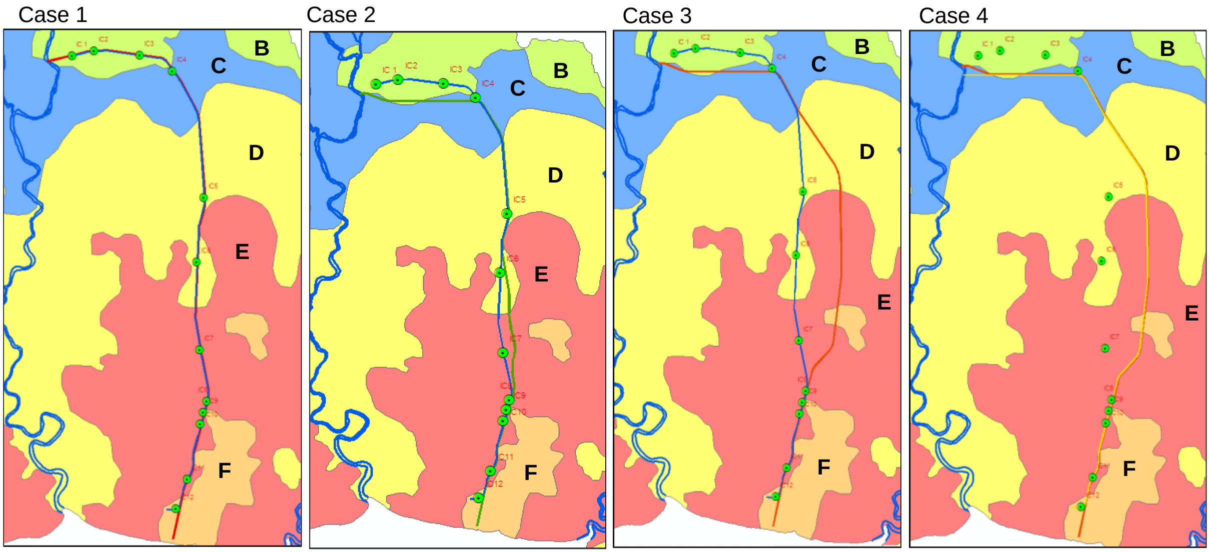
Project Efficiency

- For acceleration of the implementation, the Outer Ring Road (East section) and the Diversion Channel should be constructed through the combined project.

2) Comparison of the Alignments

In this comparative study, outline of the four cases of alignment is described below.

- Case 1: the Diversion Channel runs outside (east side) along the original alignment of the Outer Ring Road. But the number of relocation may be large, and some of them are immovable facilities.
- Case 2: the Diversion Channel runs 3~5 km apart from the Outer Ring Road at some sections to reduce the number of relocation caused by the Diversion Channel in order to keep the balance between hydraulic function, structural function and environmental and social impact.
- Case 3: the Diversion Channel runs apart more from the Outer Ring Road at some sections to minimize the number of relocation caused by the Diversion Channel. However, it may be necessary to compare this case to the other cases related to the possibility of integrated construction.
- Case 4: combined alignment of the Diversion Channel and the Outer Ring Road is newly created to minimize the number of relocation caused by the combined project. However, FS of the Road and EIA may have to be reviewed.



Legend	B	C	D	E	F
Soft Clay	3-6m	6-10m	10-14m	14-18m	>18m
Wn	20-40%	40-60%	60-80%	80-100%	>100%
LL	20-40%	40-60%	60-80%	80-100%	>100%
PI	10-20%	20-30%	30-50%	50-60%	>60%
γt	1.75-1.85t/m	1.65-1.75t/m	1.55-1.65t/m	1.45-1.55t/m	<1.45t/m
Area	6,171.75km^2	4,920km^2	6,186.50km^2	3,019km^2	674.75km^2

※A～F:A graph showing the plane distribution of soft clay with parameters of soft clay layer's thickness, moisture content etc., Publication of Kasetsart University

Source : JICA Study Team

Figure 2.3.3 Alignment of each case and soil condition

Table 2.3.2 Results from the comparison of the alignments

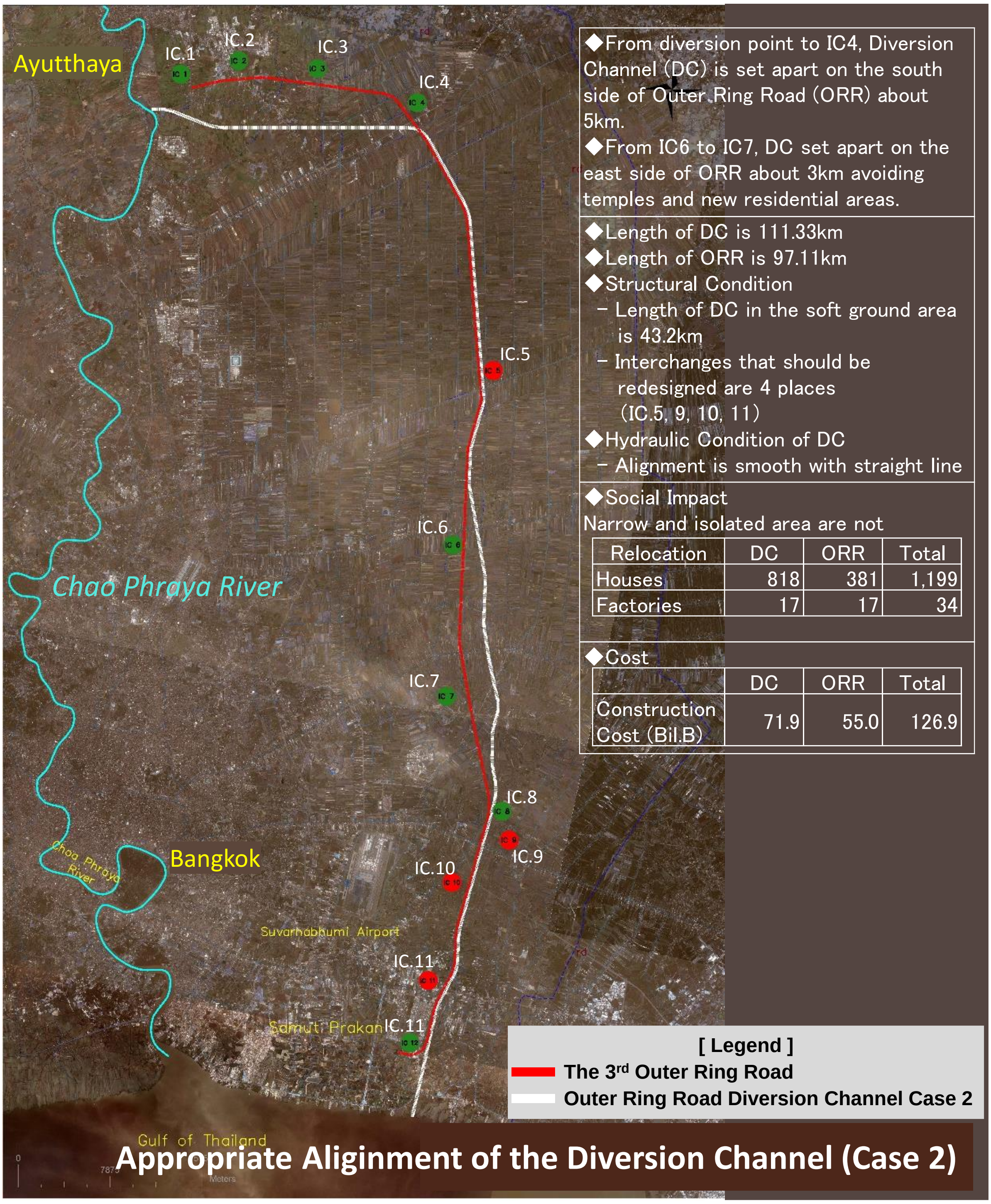
Case		Case 1	Case 2	Case 3	Case 4
Engineering	Channel Length (D. C.)	114 km B	111 km A	114 km B	114 km B
	Road Length (R. R.)	97 km A	97 km A	97 km A	102 km B
	Structural Condition (D. C.)	Length of soft clay zone: 44 km A	Length of soft clay zone: 43 km A	Length of soft clay zone: 65 km B	Length of soft clay zone: 65 km B
	Hydraulic Condition (D. C.)	Not smooth in the north part B	Smooth A	Smooth A	Smooth A
	Sub-Total Score	B	A	B	C
Social Impact	Relocation of House	Many (100)* C	Moderate (60)* B	Small (51)* A	Small (43)* A
	Relocation of Factory	Many (100)* C	Moderate (71)* B	Small (51)* A	Moderate (67)* B
	Sub-Total Score	C	B	A	A
Environmental Impact		Almost same in 4 cases**			
Cost and Benefit	Land Cost (D.C. & R.R.)	(100)*	(99)*	(100)*	(102)*
	Construction Cost (D.C.)	(100)*	(97)*	(108)*	(108)*
	Construction Cost (R.R.)	(100)*	(95)*	(94)*	(103)*
	Total Cost	Moderate (100)* B	Low (96)* A	Moderate (101)* B	High (105)* C
	Benefit	Almost same in 4 cases			
	Sub-Total Score	B	A	B	C
Total Score			A		

*Note: Index number compared to Case 1

**Note: EIA of the Ring Road needs to be revised in Case 4.

Source : JICA Study Team

In this study, RID's project evaluation aspects such as "Engineering", "Social Impact", "Environmental Impact" and "Cost and Benefit" are applied to compare the alignment alternatives. From comprehensive evaluation, the Case 2 alignment is selected as the optimum plan, based on each sub-total score of the respective alignment alternatives. The linear form is shown in Figure 2.3.4. Figure 2.3.5 shows the fully integrated case (Case 1), which was the initial plan.



◆From diversion point to IC4, Diversion Channel (DC) is set apart on the south side of Outer Ring Road (ORR) about 5km.

◆From IC6 to IC7, DC set apart on the east side of ORR about 3km avoiding temples and new residential areas.

◆Length of DC is 111.33km

◆Length of ORR is 97.11km

◆Structural Condition

- Length of DC in the soft ground area is 43.2km
- Interchanges that should be redesigned are 4 places (IC.5, 9, 10, 11)

◆Hydraulic Condition of DC

- Alignment is smooth with straight line

◆Social Impact

Narrow and isolated area are not

Relocation	DC	ORR	Total
Houses	818	381	1,199
Factories	17	17	34

◆Cost

	DC	ORR	Total
Construction Cost (Bil.B)	71.9	55.0	126.9

[Legend]

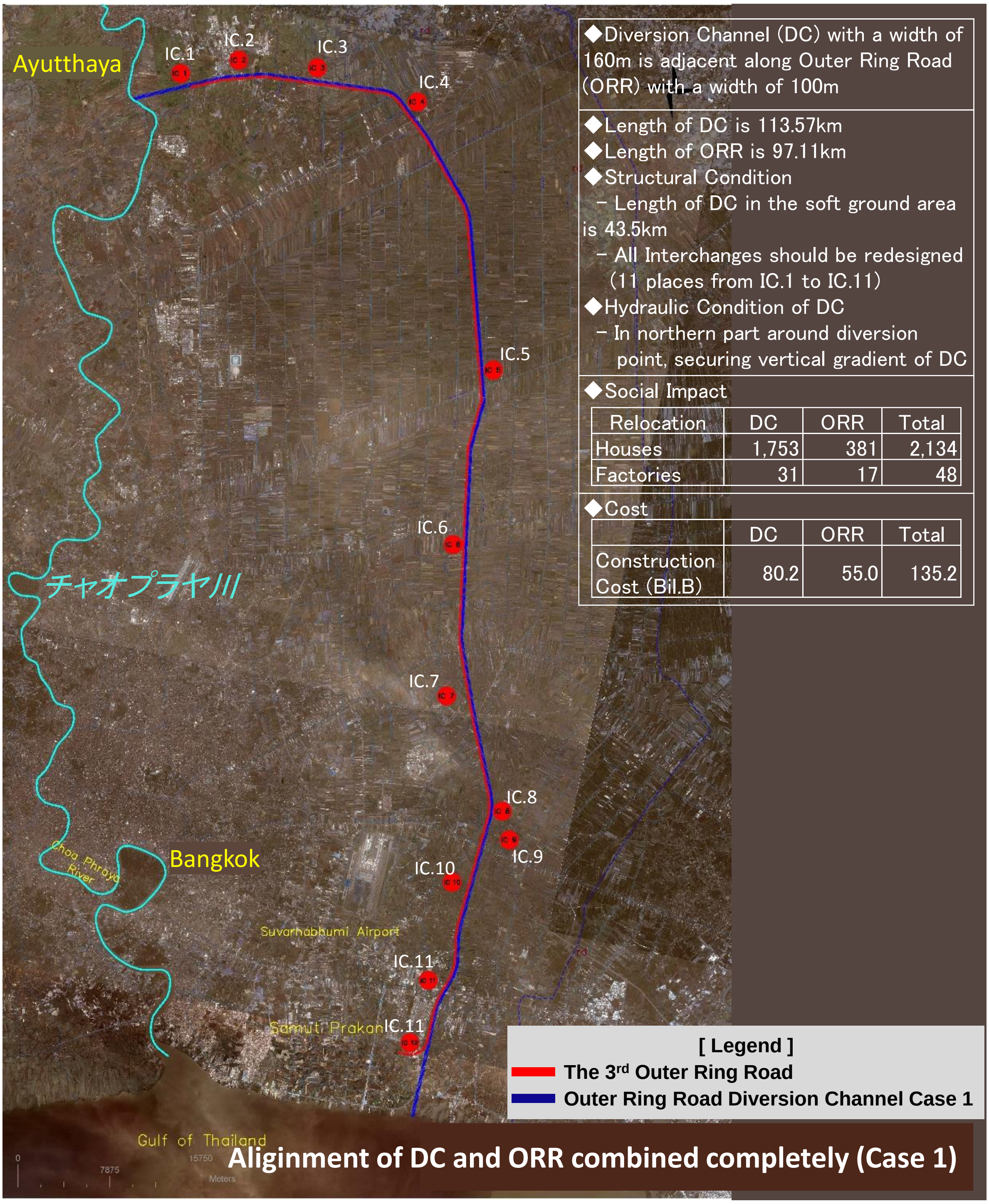
🟥 **The 3rd Outer Ring Road**

⬜ **Outer Ring Road Diversion Channel Case 2**

Appropriate Aliginment of the Diversion Channel (Case 2)

Source : JICA Study Team

Figure 2.3.4 Optimum case（Case2）



◆Diversion Channel (DC) with a width of 160m is adjacent along Outer Ring Road (ORR) with a width of 100m

◆Length of DC is 113.57km

◆Length of ORR is 97.11km

◆Structural Condition

- Length of DC in the soft ground area is 43.5km
- All Interchanges should be redesigned (11 places from IC.1 to IC.11)

◆Hydraulic Condition of DC

- In northern part around diversion point, securing vertical gradient of DC

◆Social Impact

Relocation	DC	ORR	Total
Houses	1,753	381	2,134
Factories	31	17	48

◆Cost

	DC	ORR	Total
Construction Cost (Bil.B)	80.2	55.0	135.2

[Legend]

🟥 **The 3rd Outer Ring Road**

🟦 **Outer Ring Road Diversion Channel Case 1**

Aligninment of DC and ORR combined completely (Case 1)

Source: JICA Study Team

Figure 2.3.5 Reference: Fully integrated case (Case 1)

(3) Longitudinal and cross section profile

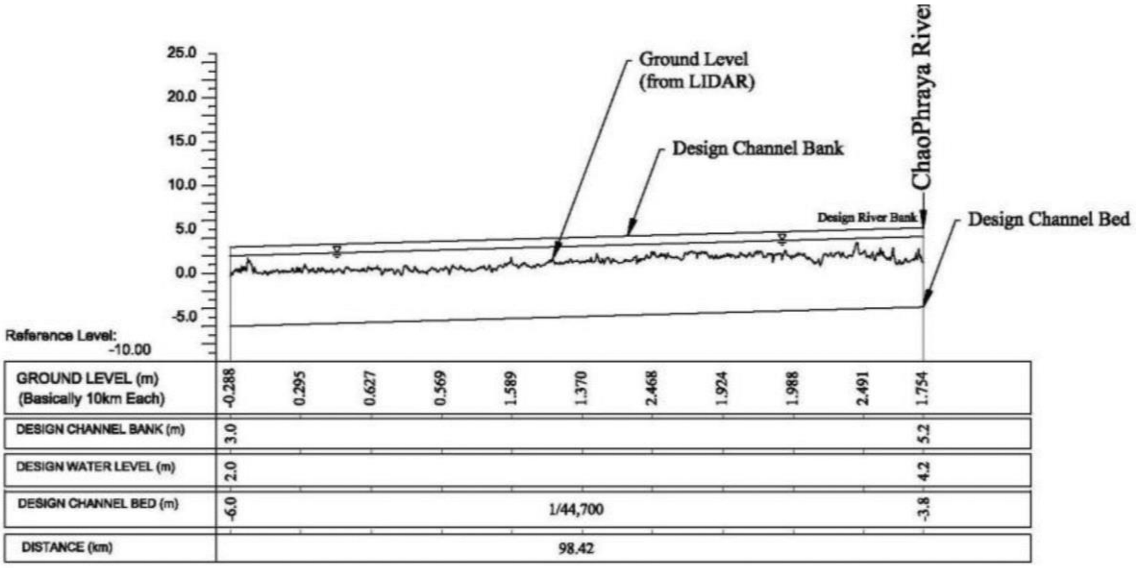
(A) Determined profiles

Longitudinal and cross section profile are set based on the alignment in the preceding paragraph as shown in Table 2.3.4 with reference to the way of thinking in JICA Master Plan.

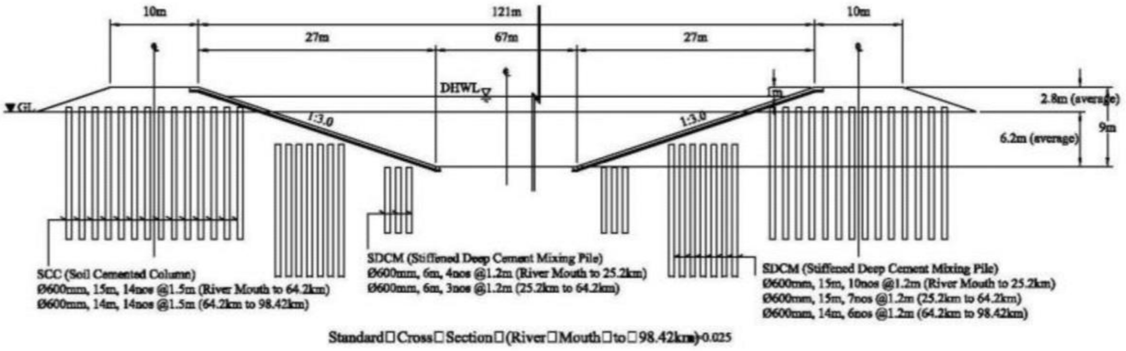
Table 2.3.3 Specified data on Longitudinal and cross section profile

Items	JICA MP	This Study
Free board	1.0m	1.0 m, follow MP According to Japan's " Cabinet Order concerning Structural Standards for River Management Facilities, etc.", the Free board required for the 500 m^3/ s is 1.0 m.
Width of top of embankment	10m	10m, follow MP
	Follow Feasibility Study of Eastern Diversion Channel by RID	
Banking slope	1:3, follow Feasibility Study of Eastern Diversion Channel by RID	1:3, follow MP According to Japan's " Cabinet Order concerning Structural Standards for River Management Facilities, etc.", the Banking slope 1: 3 is standardized
Design High Water Level (DHWL)	Set up as a height obtained by connecting DHWL of the upstream and downstream end of the channel ・Downstream end: : EL+2.0m - Highest Tidal level in 2011 ・Upstream end : EL+4.2m - Flood remarks at upstream end in 2011 flood	Follow MP ・Downstream end: : EL+2.0 m - Highest tidal level in 2011 flood ・Upstream end : EL+4.4m - Reflection of intake point - Flood remarks at upstream end in 2011 flood
Longitudinal gradient	1/44,700 Set up dividing the difference of DHWL between upstream and downstream end of the channel by the length of the channel.	1/44,100 Redesigned considering modified alignment of the Diversion Channel based on the conception in MP.

Source : JICA Study Team



Longitudinal Section of Outer Ring Road Diversion Channel (O500-1)



Cross Section of Outer Ring Road Diversion Channel (O500-1)

Source : Final report of "Project on a Comprehensive Flood Management Plan for the Chao Phraya River Basin Sept.2013"

Figure 2.3.6 Longitudinal and cross section profile in JICA Master Plan

(B) Determining longitudinal and cross section profile

Longitudinal and cross section profile of Outer Ring Road Diversion Channel has been determined based on the following procedure.

Primary setting: Longitudinal and cross section profile were set based on the result of uniform flow calculation using profiles set in the study of JICA Master Plan. The length and river bed slope of the channel were revised caused by the change of the channel alignment.

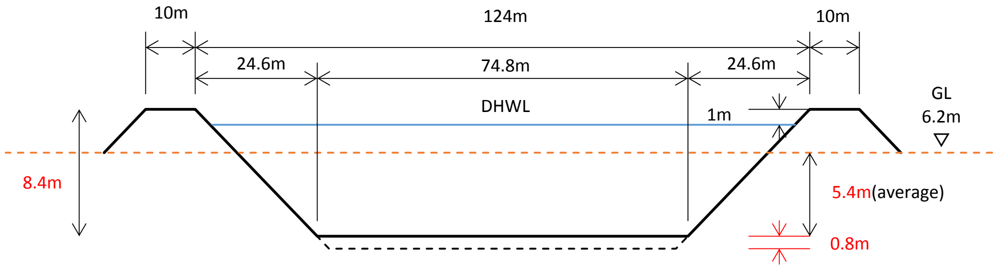
Secondary setting: Longitudinal and cross section profile have been revised based on the result of unsteady flow calculation using primary setting profile. Unsteady calculation was conducted using simulation software "MIKE-11".

Channel profile setting at the estuary: In the estuary, the height of the channel will be lower than the sea bed. Therefore, in order to prevent the sedimentation of the drift sand on the channel bed, the height of the channel bed at the estuary has been set as high as possible. With the above, longitudinal and cross section profile of the channel at the estuary has been set so that maintenance of the channel would be relatively easy.

Setting longitudinal and cross section profiles of the Diversion Channel was conducted step by step, in order to make the channel efficient and easy to maintain. Details are described in “Chapter 1.3 Cross-Section of the Outer Ring Diversion Channel” and “Chapter 1.4 Discussion of river-mouth of the Outer Ring Road Diversion Channel” of the Supporting Report.

3) Primary setting

Primary setting by uniform flow calculation was conducted as following. Roughness coefficient was set to 0.025 based on the study of JICA Master Plan.



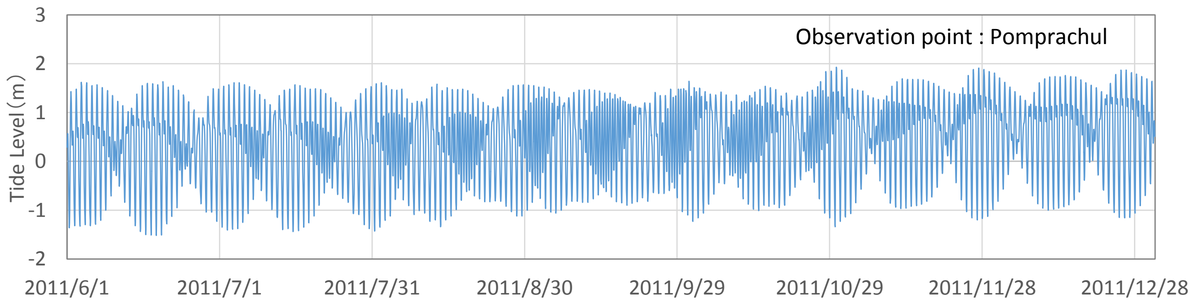
Target Discharge m^3/s	Roughness Coefficient	River Bed Slope (1/I_B)	Water Depth m	Width between both embankment m	Width of River Bed m	Cross Section Area m^2
500	0.025	44,00	7.2	124	74.8	694

Source : JICA Study Team

Figure 2.3.7 Primary setting of Diversion Channel cross section

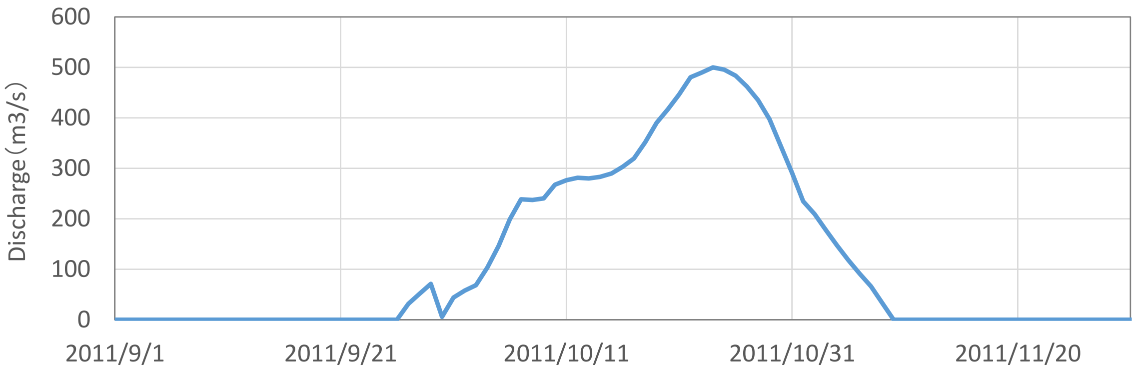
4) Secondary setting

In the secondary setting, required cross section area was checked by one-dimensional unsteady flow calculation using primary set cross sections. Tide level at the downstream end of the Diversion Channel input to the unsteady flow calculation model is shown in figure 2.3.8, and inflow hydrograph at the entrance of Diversion Channel input to the model is shown in figure 2.3.9.



Source : JICA Study Team

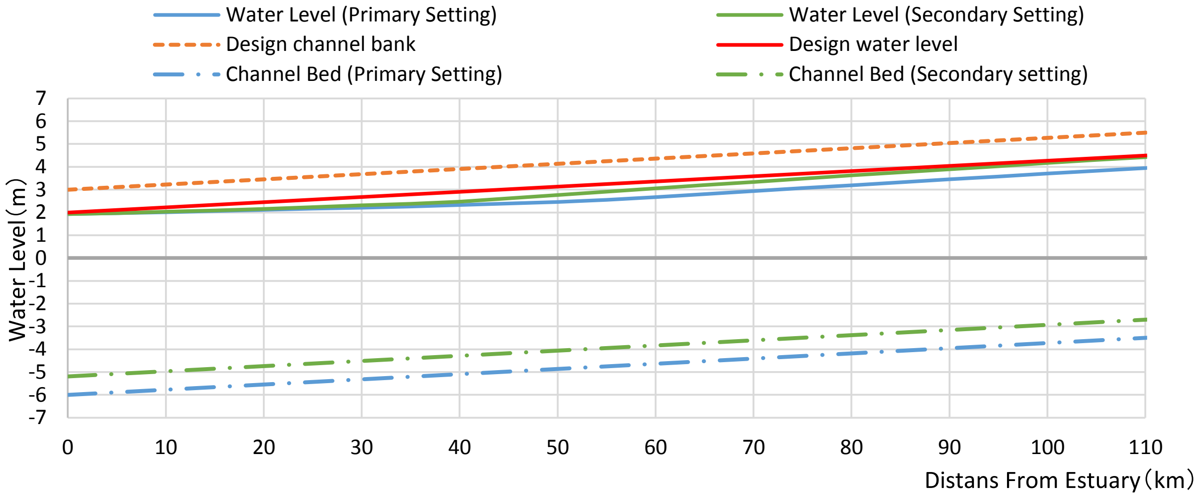
Figure 2.3.8 Tide level at the downstream end of the Diversion Cwhannel used in the calculation (Observed tide level at Pom Prachul Station)



Source : JICA Study Team

Figure 2.3.9 Inflow hydrograph at the entrance of Diversion Channel used in the calculation

The result of the secondary setting of the Diversion Channel profile is shown in figure 2.3.10. As a result of secondary setting, the channel bed height could be set 0.8m higher than the height in primary setting.



Source : JICA Study Team

Figure 2.3.10 Secondary setting of river bed slope based on non-unioform flow calculation

5) Determining channel profile at the estuary

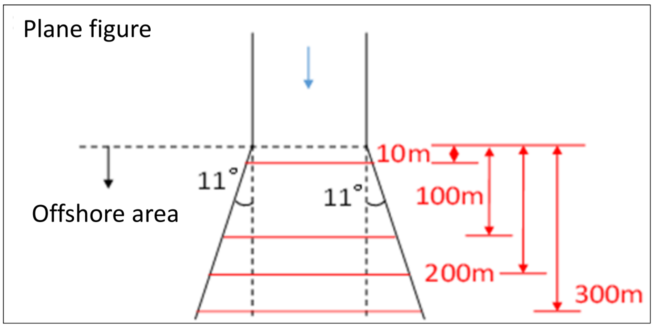
Sea bed height at the estuary is from minus 2m to minus 3m but channel bed height at the estuary is minus 5.2m. Therefore, it is necessary to excavate deeper than the current sea bed height at the downstream of the channel. And it is concerned that drift sand from offshore will accumulate on the channel bed and it will be a problem in maintenance. Because secondary set flood water level is sufficiently lower than the Design High Water Level (DHWL), in order to make maintenance easier, the height of the channel bed was set as high as possible making channel bed slope level around estuary.

The width of the channel around downstream end (offshore) was set to the shape spreading in the downstream direction at an angle of 11 degrees in a plane shown in figure 2.3.11.(refer to Japanese “Guidance on the study of river channel planning” published by Sankaido.)

Regarding longitudinal length of the channel in the offshore area that will net reduce flow capacity of the channel, unsteady flow calculations were conducted in the following cases, and it was confirmed that even in the case of 10m channel length, flow capacity of the channel will not be reduced.

- In case that the length of the channel downstream of the gate that will be installed around estuary is 10m
- In case that the above length is 100m, 200m and 300m

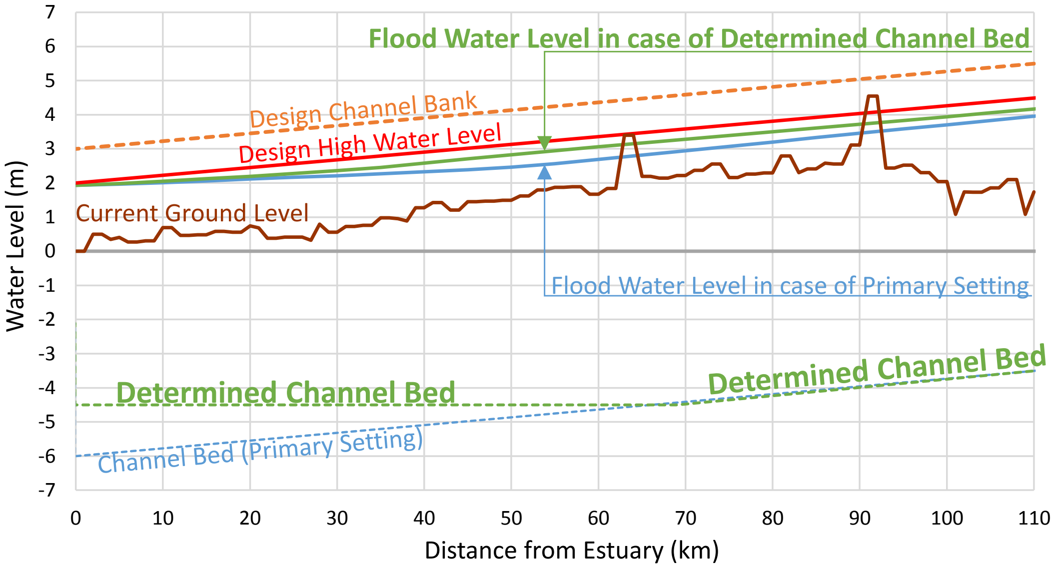
Details related to the above study are described in "Chapter 1.3 Cross-Section of the Outer Ring Diversion Channel" and "Chapter 1.4 Discussion of river-mouth of the Outer Ring Road Diversion Channel" of the Supporting Report.



Source : JICA Study Team

Figure 2.3.11　Setting of the Diversion Channel width around downstream end

The longitudinal profile of the channel bed is shown in figure 2.3.12. The height of the channel bed around estuary has been set so that the flood water level does not exceed Design High Water Level with the unsteady flow calculation. To determine this height, unsteady flow calculations were conducted in some cases that the height of the channel bed is increased from minus 6.0 m at interval of 50cm. From these trial calculations, it has been clear that flood water level does not exceed Design High Water Level in case that channel bed height is less than minus 4.5 m. Based on the above study, the height of the channel bed has been set up to minus 4.5 m from the downstream end to 69km point of the channel.

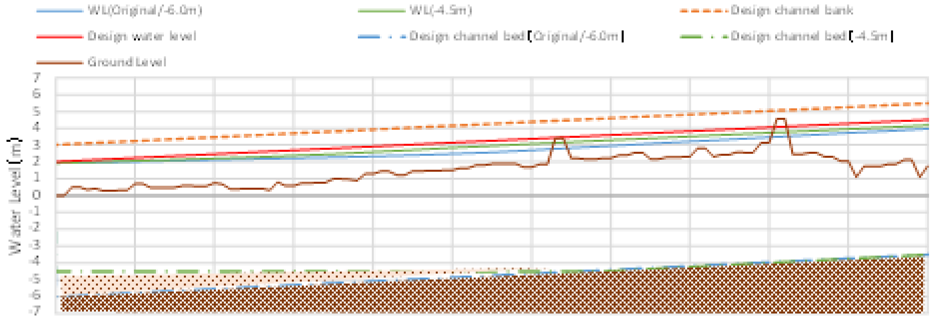


Source : JICA Study Team

Figure 2.3.12　Longitudinal profile of the Diversion Channel

6) Designed longitudinal section and cross section

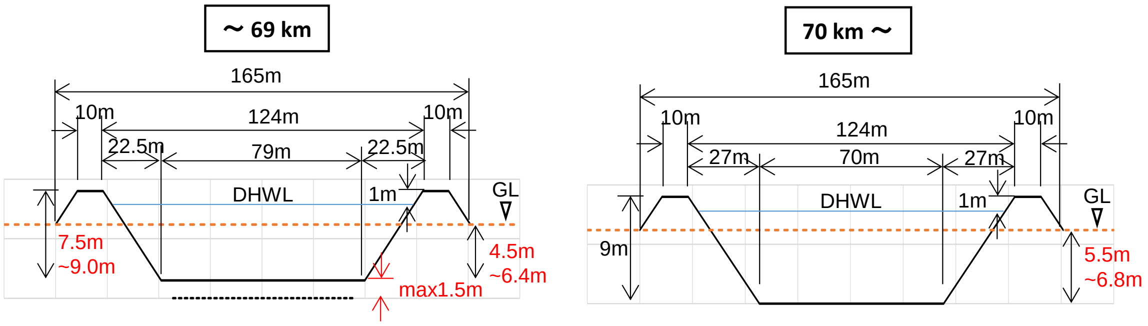
Based on the above study, longitudinal section and cross section of Outer Ring Road Diversion Channel have been determined as shown in figure 2.3.13 and 2.3.14.



Ground Level (Basically 10km Each)	0.00	0.70	0.74	0.56	1.28	1.49	1.68	2.22	2.22	2.29	3.11	2.04	1.74	2.85
Design Channel Bank (m)	3.00	3.23	3.45	3.68	3.91	4.13	4.36	4.56	4.59	4.81	5.04	5.27	5.49	5.50
Design Water Level (m)	2.00	2.23	2.45	2.68	2.91	3.13	3.36	3.56	3.59	3.81	4.04	4.27	4.49	4.50
Design Channel Bed (m)	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.50	-4.41	-4.19	-3.96	-3.73	-3.51	-3.50
Excavation Depth (m)	4.5	5.2	5.2	5.1	5.8	6.0	6.2	6.7	6.6	6.5	7.1	5.8	5.2	6.4
Accumulated Distance (km)	0	10	20	30	40	50	60	69	70	80	90	100	110	110.3

Source : JICA Study Team

Figure 2.3.13 Designed longitudinal section

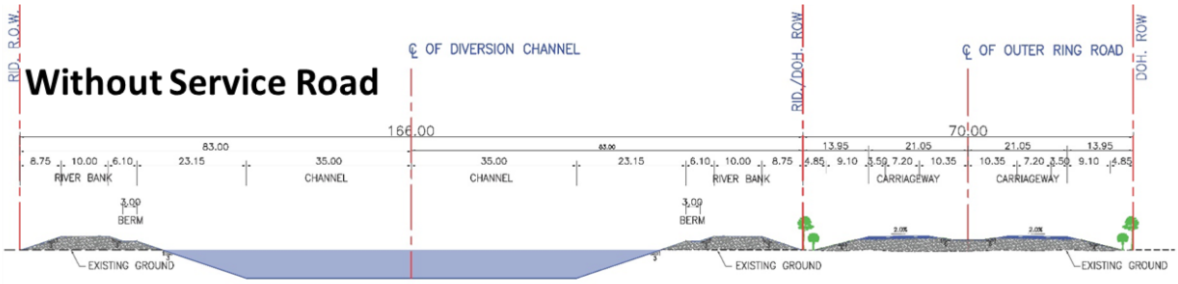


Source : JICA Study Team

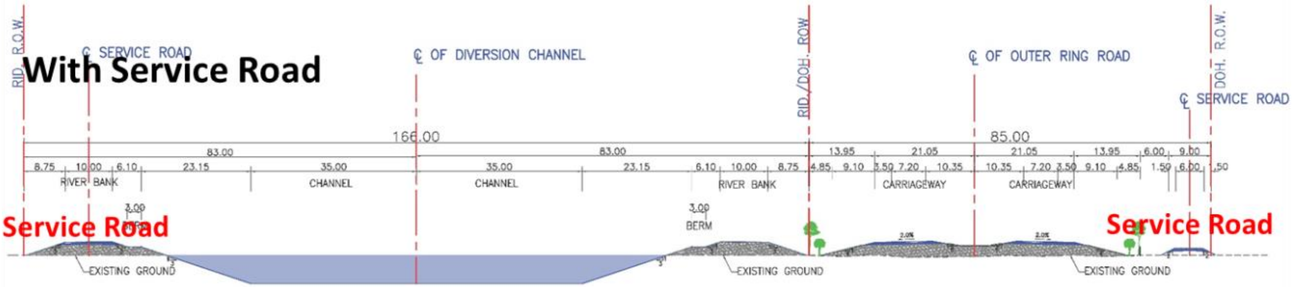
Figure 2.3.14 Designed cross section

(4) Combined structure of Diversion Channel with Outer Ring Road

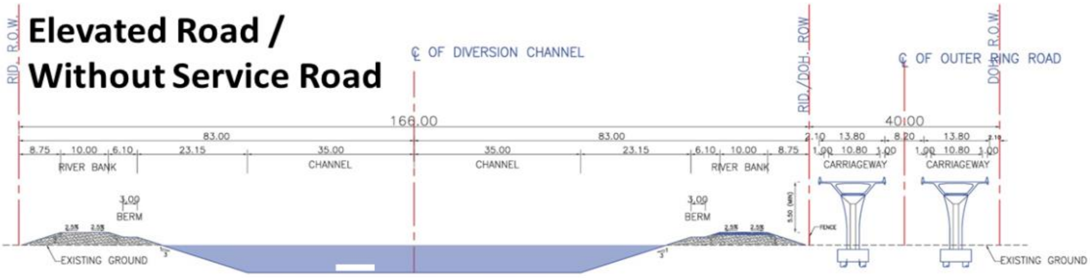
As a result of the above studies, alignment, longitudinal profile including river bed slope and cross section of the Outer Ring Road Diversion Channel have been determined. Based on these results, combined structure of the Diversion Channel with the Outer Ring Road has been determined as shown in the following figures.



(Standard cross section of Diversion Channel adjacent to the east side of Outer Ring Road)



(Standard cross section of Diversion Channel adjacent to the east side of Outer Ring Road using left side channel embankment as the service road)



(Standard cross section of Diversion Channel adjacent to the east side of Outer Ring Road to be elevated structure in southern part)

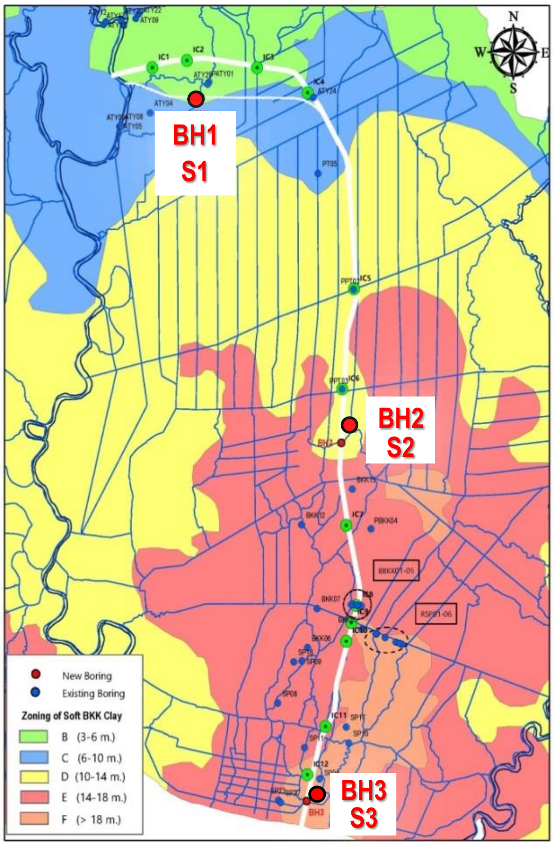
Source: JICA Study Team

Figure 2.3.15 Combined structure of Diversion Channel with the Outer Ring Road (Cross section)

2.4 Basic Design of Main Structure

2.4.1 Soil conditions

In order to study the stability of the ground in the construction area and the potential for reuse of the excavated soil, soil surveys and soil testing were carried out at three points, in the upstream, midstream and downstream areas of the section in which the Outer Ring Road Diversion Channel is planned. The results of the soil testing on the soil borings and samples taken from the boreholes (disturbed samples taken using an STP sampler and little disturbance samples taken using a TW sampler) were used to carry out stability analysis of the ground at the site, and the disturbed samples taken from a test pit excavated beside the boring point will be used as material to determine the possibility of its reuse as filling material (for the embankments to be constructed on either side of the diversion channel, and in the highway embankment for the Outer Ring Road (East section) that will run parallel to it). The locations of the soil survey sites are shown in Figure 2.4.1.

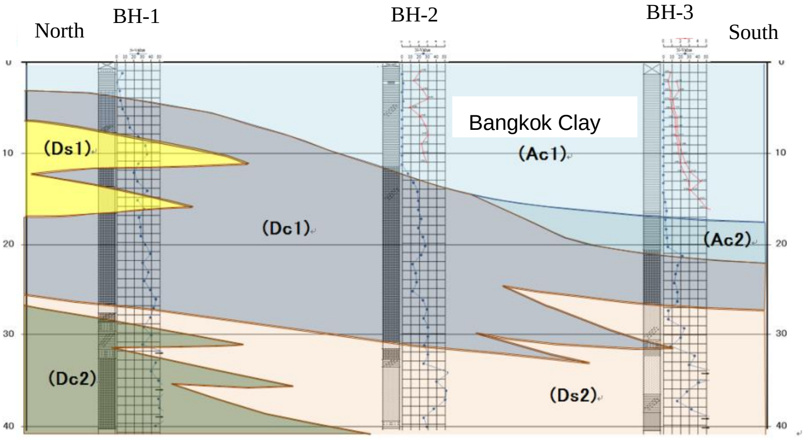


Source : Kasetsart University research

Figure 2.4.1 Bangkok clay stratum thickness distribution map

(1) Geological profile (stratum structure)

The results of the soil borings, as shown in Figure 2.4.2, indicate that the soil of the target area is soft alluvial clay known as Bangkok Clay, overlying diluvial hard clays, interfingered with sandy strata. The stratigraphy and characteristics are shown in Table 2.4.1.



Source: JICA Study Team

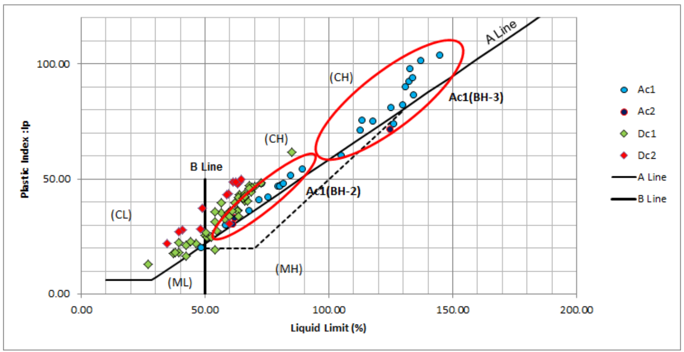
Figure 2.4.2 Estimated geological cross-section

Table 2.4.1 Stratigraphic chart

Period		Symbol	Features	N value range (average)
Cenozoic Quaternary	Alluvial epoch	Ac1	Extremely soft cohesive soil from dark gray to dark blue-gray in color, with clay as the main component, also known as Bangkok Clay. Distribution is thin (2 m) at the north BH-1 site and thick (18 m) at the south BH-3 site.	0-2 (0)
		Ac2	A green-gray clay rather low in moisture content, lying in a stratum roughly 4 m thick underlying the Ac1 around the BH-3 site.	2-4 (3)
	Pleistocene epoch	Dc1	A cohesive soil distributed widely underlying the Bangkok Clay, low in water content and yellow-gray to milky grayish-brown in color. Has a sandy layer enclosed inside.	3-45 (22)
		Ds1	A brownish-gray sandy layer distributed some 8 to 17 m below ground level around the BH-1 site. The upper part contains coarse sand and the lower part a silty component.	24-35 (30)
		Ds2	A dark brown sandy layer that is thin around the BH-1 site and becomes thicker towards the south. The main component is fine sand. Around 36 m below ground level it alternates with layers of coarse sand to fine gravel.	6-67 (34)
		Dc2	Hard clay ocher in color, distributed 28 m below ground level at the BH-1 site.	39-63 (45.6)

Source: JICA Study Team

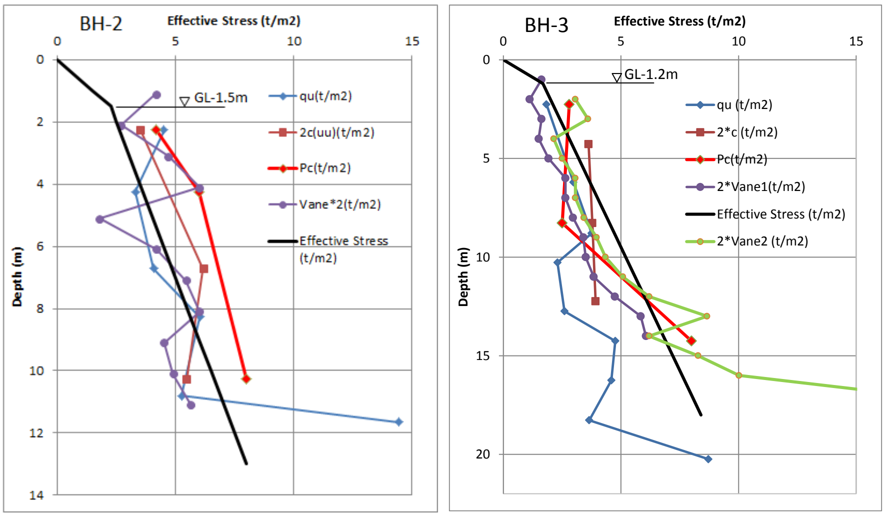
(2) Results from laboratory soil testing



Source: JICA Study Team

Figure 2.4.3 Plasticity chart

Soil testing was carried out on the standard penetration test samples extracted at 1.0 m intervals and on little disturbance specimens sampled from the boreholes. The results of the physical testing carried out using the standard penetration test samples were mapped onto a plasticity chart (Figure 2.4.3). As the plasticity chart indicates, Bangkok Clay (Ac1) is a clay with a high moisture content (high compressibility), and with a clear difference in distribution at BH-2 and BH-3 (At BH-3 the liquid limit is 100-150%, at BH-2 the liquid limit is 50-100%, meaning that the compressibility at BH-3, which is further from Line B, is higher). Mechanical properties tests carried out were unconfined compression test, triaxial compression test (UU conditions) and consolidation test. Graphs comparing the results of each type of test, shear strength using the Vane test and effective stress are shown in Figure 2.4.4.



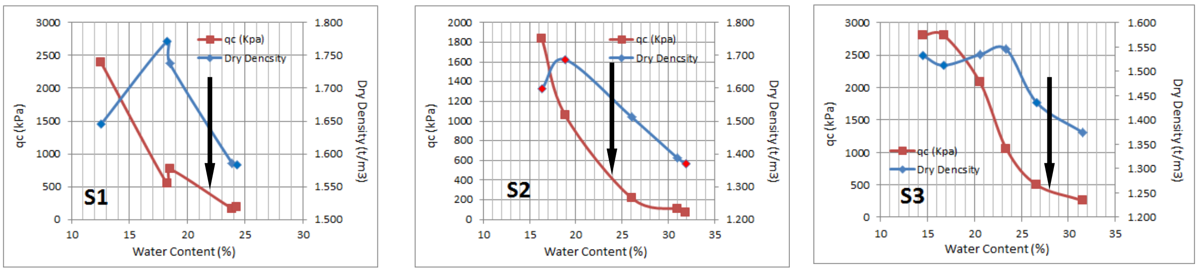
Source: JICA Study Team

Figure 2.4.4 Results from effective stress and mechanical properties testing

At BH-2 there is a lot of variation, but values are distributed more or less along the effective stress line. At BH-3 on the other hand, the test result values are distributed some 20% below the effective stress, and it can be said that natural consolidation is not complete (a state of incomplete consolidation). As shown in the plasticity chart, the comparison of the Bangkok Clay in the BH-2 area and the Bangkok Clay at BH-3 area, BH-3 area clay has a higher moisture content and a higher compressibility and it can be said that compression under natural conditions is in an incomplete state. The result of mechanical test was interpreted together with previous boring test result and then reflected slip calculation. The result is shown in 4.3.2 "Condition of the Study", (2) "Ground condition" of Supporting report. Results of mechanical test are using for land slip calculation considered with existing test result of existing boring survey. Organized graph of test results are shown in 4.3.2 Condition of Consideration, (2) ground condition of Chapter 4 Basic Design of the Outer Ring Road Diversion Channel in Supporting Report.

(3) Bangkok Clay mixing test

In order to study the possibility of the huge amount of Bangkok Clay generated in the construction of the diversion channel being reused as filling material, improvement testing was carried out involving mixing the clay with a good-quality purchased sand and mixing it with a quicklime/cement. Specimen of the test was made using by mixer. Results showed that sufficient improvement effect could be obtained with the lowest proportion of sand, a clay:sand ratio of 2:1. The test results are shown in Fig. 2.4.5. Each sample satisfies $q_c \geqq 400$ kPa where the moisture content is higher than the maximum dry density moisture content (moisture content indicated by the black arrow in the graph).



Source: JICA Study Team

Figure 2.4.5 Results of compaction testing and cone penetration testing (clay:sand = 2:1)

The CBR test has been done by specimen, quicklime was added in the proportion of 5%, 7% and 9% by weight. CBR test results of the quick lime mixing test for S2 are shown in below Table 2.4.2

Table 2.4.2 CBR of Quick Lime Mixing for S2
(clay:sand=2:1 and Quick Lime = 5%, 7%, 9%)

Quick lime ratio	5%	7%	9%
S2 Value of CBR	42.42	50.54	63.55

Source : JICA Study Team

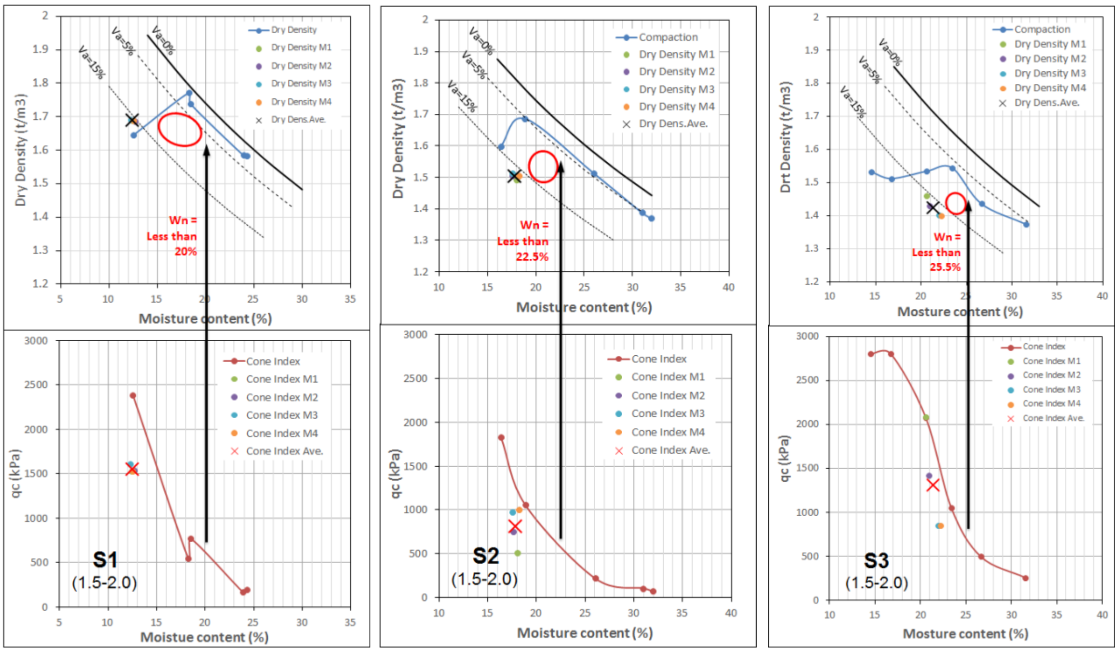
As the 8% cement mixture did not achieved the target for unconfined compression strength of 0.75 MPa, the use of mixed soil material as a roadbed material needs additional consideration such as cost comparison with increase cement percentage and purchasing good material, etc.

(4) Specific character of hand-mixed material for embankment

In the construction of the diversion channel embankment, it is considered that strict quality control is not required (best mixing way is by stabilizer) and it is surmised that blocks of clay will remain. Taking this situation into consideration, the following additional tests were carried out.

- Cone penetration test, unconfined compression test, triaxial compression testing of compacted samples in which 1.5-2 cm beads of clay remained
- Cone penetration testing of compacted samples in which 3.0-4 cm lumps of clay remained

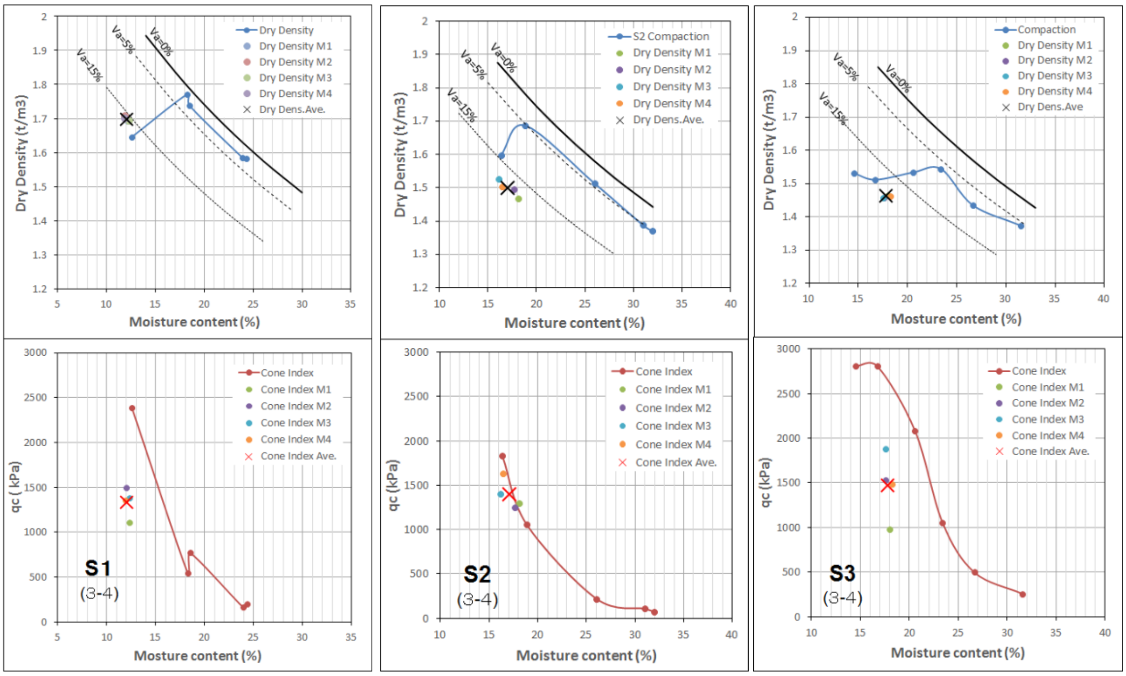
The results of the cone penetration testing of compacted samples containing lumps of clay with size 1.5-2.0 mm are shown in Fig. 2.4.6.



Source: JICA Study Team

Figure 2.4.6 Results of compaction/cone index testing
(Testing on samples containing lumps of clay with size 1.5-2.0 cm)

It is recognized that the cone index generally tends to be around 30% lower than the strength obtained by mixing in a mixer. The results obtained from samples containing lumps of clay measuring 3.0-4.0 cm are shown in Fig. 2.4.7. Compare to containing lumps of clay 1.5-2.0, the value of cone penetration tests shows more variations and lower results.



Source: JICA Study Team

Figure 2.4.7 Results of compaction/cone index testing
(Testing on samples containing lumps of clay with size 3.0-4.0 cm)

(5) Evaluation of the stability of the diversion channel embankment using mixed soil

In order to evaluate the stability of the diversion channel embankment, consolidated undrained triaxial compression testing was carried out. The test results are shown in Table 2.4.3. The samples were mixed both by hand and mixer in the ratio of clay : sand = 2:1.

Table 2.4.3 List of results of triaxial compression testing (CUB)

Test item	S1		S2		S3
Mixing Method	Mixer	Hand	Mixer	Hand	Mixer
Moisture content (%) (Before testing)	13.49	27.01	20.12	35.33	51.85
Density (t/m^3)	2.057	2.01	1.933	1.94	1.627
Effective shear stress C’cu (kPa)	25.86	26.30	2.61	22.97	16.01
Effective shear angle ⌀'cu (°)	19.81	22.88	31.62	18.07	24.68
Shear stress C’cu (kPa)	15.34	14.60	10.34	12.63	7.80
Shear angle ⌀'cu (°)	19.27	19.94	18.98	17.83	20.85

Source: JICA Study Team

With respect to the hand-mixed samples, as the diameter of the triaxial compression test mold is only 3.7 cm, testing was carried out only on samples containing beads of clay no larger than 1.5 to 2 cm.

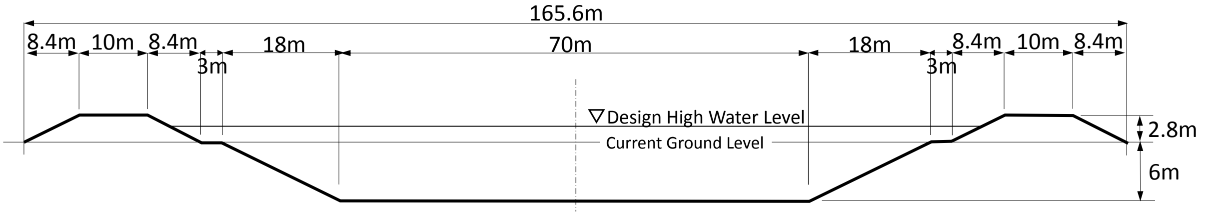
2.4.2 The Outer Ring Road Diversion Channel

(1) Cross section of the structure

1) Design Cross section of the Diversion Channel

The design cross section of the Diversion Channel for the design discharge capacity Q=500 m^3/s is shown in Figure 2.4.8. The channel is designed to be excavated approximately 6.0 m below the present ground elevation with a width B=70 m. Embankment on the two sides are 2.8 m above the existing ground. Side slope is 1:3 and an interval space of 3.0 m will be set on present ground elevation between the embankment and the side slope.

In Outer Ring Road Diversion Channel longitudinal plan, riverbed height is set highly same as seabed height, considering estuary's operation and maintenance. As a result, a section from the estuary to the point located at a distance of 69 km from the estuary has no slope of riverbed (EL-4.5m), while a section from the point to upper stream has longitudinal slope=1/46,600. Therefore in regard to cross slope, existing ground is excavated 4.5-6.4 m at the former section and is excavated 5.5-6.8 m at the latter section. At both sides of all sections, embankment (h=2.8m) is constructed in this plan. At the higher riverbed section, excavation height changes longitudinally. For this reason, cross section shape of this study are set as deeper excavation shape than other the other areas and the excavation height is set as 6.0 m, it is general height. Besides excavation height is set as 2.8 m, excavation slope is set as 30%. At the both sides, berg (height=3.0 m) is constructed.



Source: JICA Study Team

Figure 2.4.8 Design cross section of the Diversion Channel

2) Countermeasure against soft ground

Along the alignment of the Outer Ring Road Diversion Channel, soft ground layer gets thicker as it goes south. Therefore, countermeasures against landslide and differential settlement are essential in construction of embankments. In this study, the Outer Ring Road Diversion Channel is divided in three parts, namely north, central and south parts, in accordance with their soft ground conditions.

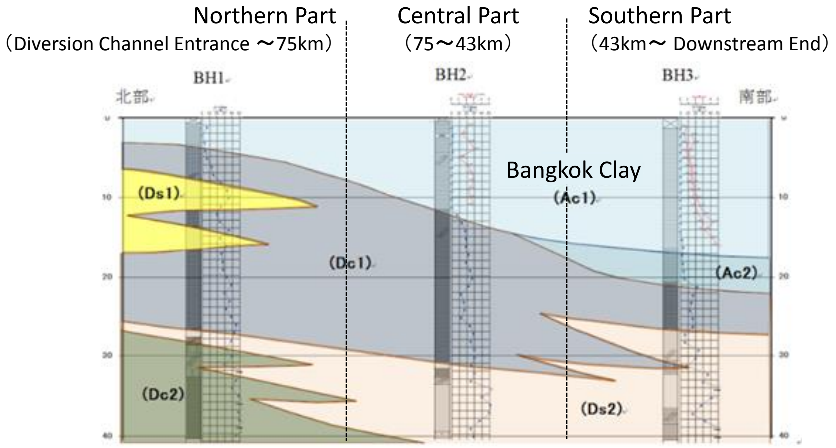


Figure 2.4.9 Estimated geological longitudinal section (indicated again)

Soil parameters were determined by considering the result of the previous survey and the results of the new geological survey, which was conducted at one site of each part. Strength parameters were determined by considering the relation between the depth and the result of unconfined, triaxle compression tests. It was assumed that strength increases with depth. Wet density and consolidation characteristic were determined as average of geological survey value. Selected results for each part are shown in Table 2.4.4.

Table 2.4.4 Construction method for soft ground

Part	Without-method				With method	
	Slipping safety coefficient （after construction）	Residual settlement	Final settlement	Time for settlement (until 90% consolidation)	Slipping countermeasure	Settlement countermeasure
North	1.51	9.2cm	17.8cm	3410 days	—	—
Central	**1.11** **NG**	**30.4cm** **NG**	58.8cm	4400 days	SCC method φ800	PVD Method (3.0m pitch in both longitude and lateral)
South	**0.50** **NG**	20.9cm	**140.0cm**	51000 days	SCC method φ800	PVD Method (1.0m pitch in both longitude and lateral)

Source: JICA Study Team

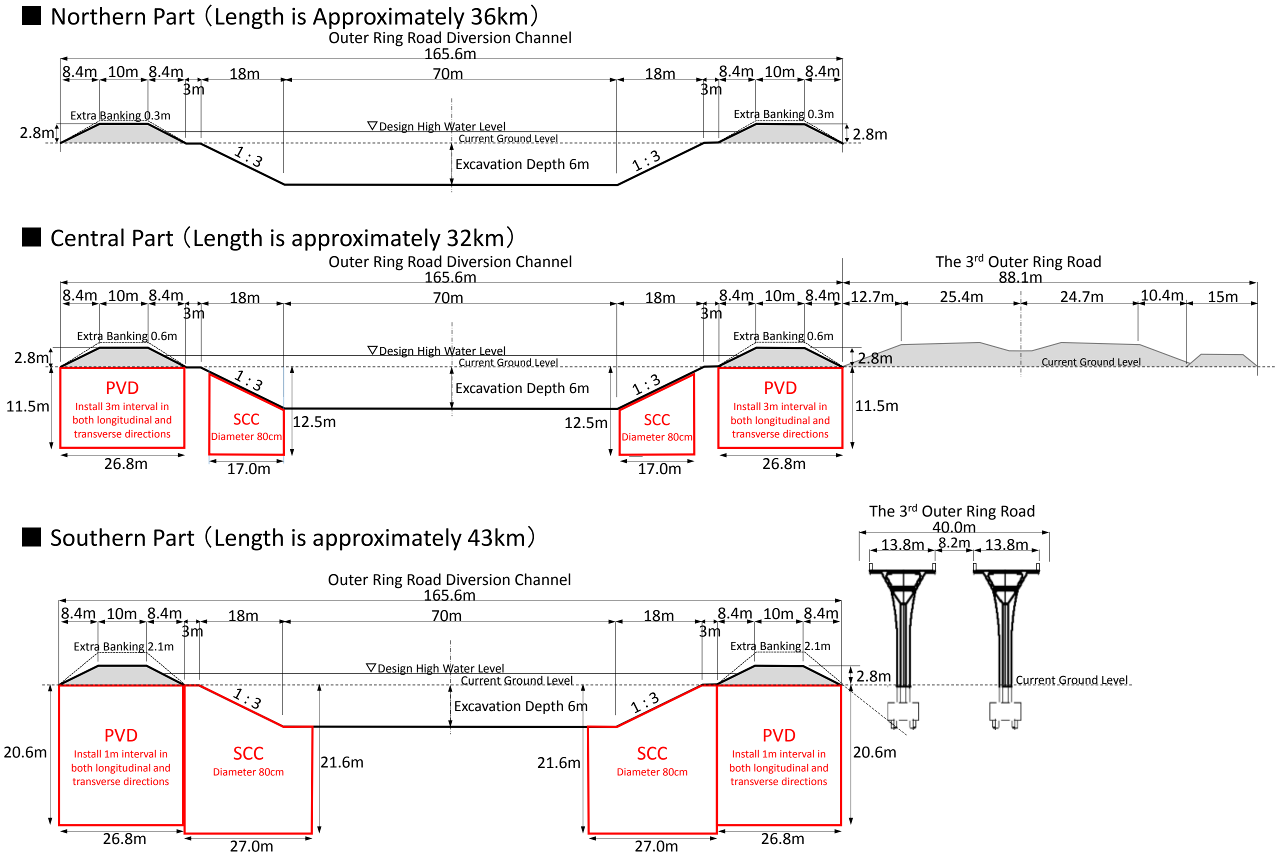
*SCC Method (Soil Cement Column Method) : To solidify ground using soil mixed with additive agent, for example cement.
*PVD Method (Prefabricated Vertical Drain Method) : To accelerate sedimentation and accelerate draining of cohesive soil by placing drain material, for example factory-made plastic.

Slipping calculation ensured that threshold value of target safety factor should be 1.5 when construction was completed. Sedimentation calculation ensured that threshold of residual settlement should be 30 cm. This value indicates allowable settlement of residual settlement volume three years after the start. Road standard is applied because some area of crest embankment is used as service road. At south part, settlement is large and embankment is conducted step by step, considering limit height of embankment. In case of non-measure, settlement is calculated assuming that embankment weight loads on the base ground instantly.

At north part, construction of the embankment was adopted together with diversion channel excavation because it is not necessary to take countermeasure for slipping or settlement for the north part. At central area, PVD Method was adopted as countermeasure, because the residual settlement exceeded 30 cm after the construction of the embankment and excavation when no countermeasure is conducted. SCC method was adopted as countermeasure against slipping at excavation slope. Construction process is as follows; 1) Countermeasure against soft ground (SCC method and PVD method) is conducted for existing ground. 2) Strength of soft ground increased and consolidation settlement is accelerated by stockpile construction at embankment area (H=3.0 m). 3) Diversion channel embankment is conducted (considering extra-banking). 4) Diversion channel excavation is conducted.

At south part, PVD method was adopted as countermeasure against consolidation settlement, while SCC method was adopted as countermeasure against slipping. That is because slipping stability at excavation slope could not be ensured and it takes time to settle because of the high final settlement quantity when countermeasure is not conducted. When examining countermeasure method, three methods were compared, PVD method to accelerate settlement, the method to increase strength of cohesive soil and to make excavation slope low pitch and Steel sheet pile method (combination with improved ground). Finally SCC method was adopted in terms of economic advantage.

Construction process is as follows; 1) Countermeasure against soft ground (SCC method and PVD method) is conducted for existing ground. 2) Excavation is conducted together with excavation soil at central area (primary excavation height = 2.5 m). 3) Diversion channel excavation is conducted. SCC was designed to arrange Cement Columns in grid patterns and reduce number of Columns in order to make Soil Stabilization Cost low. Important point is to overlap between columns. Hence two columns are put at each block to make sure to overlap columns even if construction is not accuracy.

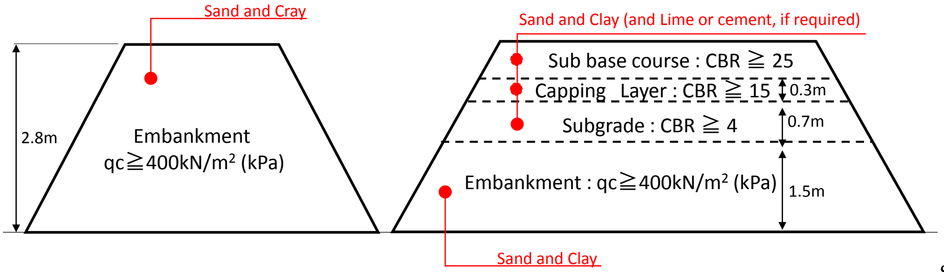


Source: JICA Study Team

Figure 2.4.10 Typical design cross section of the Diversion Channel

3) Utilization of excavated soil

Soil will be excavated in a massive volume of approximately 58 million cubic meters along the 110 km long Diversion Channel. Therefore, it is necessary to utilize the excavated soil for embankment (channel and road) as a measure to reduce soil disposal costs. An embankment construction method by mixing of the excavated soil (soft clay) with purchased sand, lime and cement on the construction site, is discussed. A laboratory experiment was conducted using the above mentioned mixed soil, to see if it is suitable as an embankment material. The suitability was confirmed using criteria of threshold value set for Channel embankment and Road respectively, as shown in Figure 2.4.11



Source: JICA Study Team

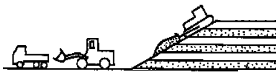
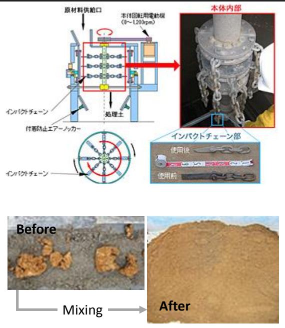
Figure 2.4.11 Threshold value for suitability of mixed soil as embankment material

Figure 2.4.11 shows methods to mix materials. As for, soil slice for stockpile method is adapted since relatively channel embankment allows a dispersion in material. For road embankment, mixing in plant method is adapted to mix well. This is because it is needed to use high quality and homogeneous materials to avoid generating differential settlement. In this study, it is assumed that the material of the channel embankment will be prepared mixing excavated soil with purchased sand and that of road embankment will be prepared mixing in the plant. Therefore, samples for the soil test were prepared assuming actual mixing methods during construction work.

Table 2.4.5 Example of mixing methods

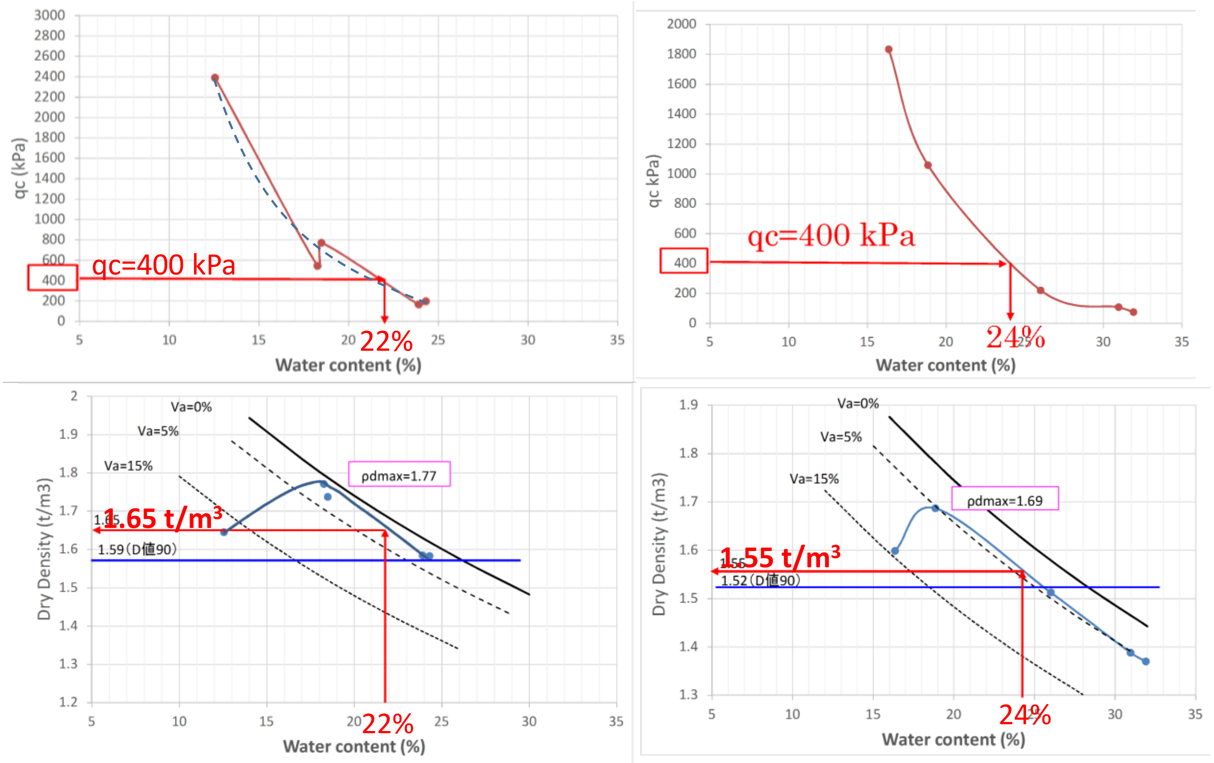
Simple mixing

Plant mixing

	Level-1	Level-2	Level-3	Level-4
	Stock-Pile	Mixing by Stabilizer	Plant Mixing	Twister Mixing (Rotary crushing and mixing)
Mixing Method	Push down stock-pile by bulldozer and drop pushed down soil about three times by wheel loader  ＜Stock-Pile Preparing Method＞ 1) Excavate clay by clamshell or Backhoe 2) Dry up excavated clay under sun shine during temporary placing and split mass clay into small pieces 3) Prepare stock-pile stacking clay and sand alternately	Mix at embanking work site by Stabilizer 	Set up stationary type plant. Clay and sand that are put into this plant will be stirred and mixed. 	
Application	This method is adopted aiming to shorten construction period and reduce construction cost.	This method is adopted as an additional process to Level-1 method if mixing using Level-1 method is insufficient.	This method is adopted to mix more carefully than Level-2 method. If clay and sand mixing is difficult, Level-4 method is adopted.	This method is adopted to mix three or more kinds of materials for example clay, sand and lime. Plant mixing except for this method can mix only two kinds of materials.

Source: JICA Study Team

Result of Cone penetration test is shown in Fig. 2.4.12 again. This test was conducted using sample made by mixing excavated clay in north and central part and purchased sand by mixer. This result show that if excavated clay is mixed with purchased sand at a ratio of 1:2, q_c (Cone Index) of the mixed soil exceeds 400 kPa with higher water content than the optimum water content. Therefore excavated clay can be used as a material of channel or road embankment if it is mixed with sand and water content of this mixed soil is adjusted.



North (S1) **Central (S2)**

Source: JICA Study Team

Figure 2.4.12 Result from the cone penetration test (Excavated soil : Sand = 2 : 1)

Meanwhile, Table 2.4.7 shows CBR test result using above mixed soil (mixer mix, clay:sand=2:1), mixed with quicklime in a ratio of 5%, 7% and 9%. All results' CBR were higher than 25 and the mixed soils are able to be use as soil of subbase course and subgrade.

Table 2.4.6 Result of CBR test (S2)

Sample No.			Physical Property Test			①Dry Density	②MAX Dry Density	①/②	CBR for Mixed Soil
			Moisture Contents	Particle Size					
				Clay+Silt	Sand+Gravel				
			%	%	%	t/m3	t/m3		
Sand (perchased)			–	4	96	–	–		–
S2	Clay(original)		–	95.43	4.57	–	–		–
	Clay2 : Sand1	+Quick Lime 5%	16.88	–	–	1.62	1.69	96%	42.42 (OK)
		+Quick Lime 7%	17.18	–	–	1.61	1.69	95%	50.54 (OK)
		+Quick Lime 9%	16.00	–	–	1.59	1.69	94%	63.55 (OK)
		+Cement 8%	16.53	–	–	1.84	1.84	100%	68.43 (OK)

Source: JICA Study Team

Roughly mixed soil sample in which block-shaped clay remain was prepared assuming that clay and sand are mixed by cutting off the stock-pile. The result of test using this sample is shown in figure 2.4.13. The compaction curve and cone index curve in the figures show the result of test using sample, mixed by mixer. The cone index's strength of the test with remaining block-shape clay is approximately 30% lower than that of the test using mixed soil by mixer. Therefore considering approximately 30%decreasing of strength, black arrow shows the result as 600 kPa of the test using mixed soil by mixer. Red circle shows target area to be achieved by compaction. The mixed soil by stock pile cut through is able to be used as soil of filled up ground for embankment of river dike and road. Additionally, even when not using mixer, it is desirable to mix soil as much as possible to homogenize the soil.

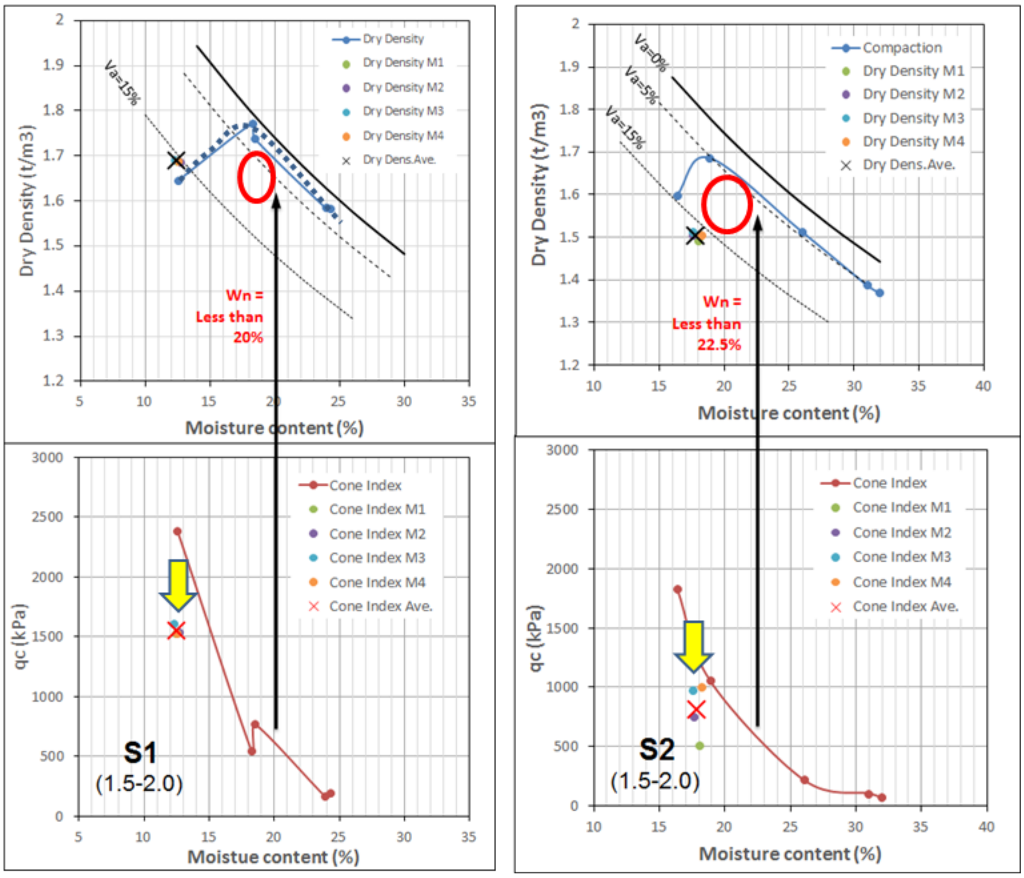


Figure 2.4.13 Result of compaction/cone index testing
(Testing on sample containing lumps of clay with size 1.5-2.0cm)

(2) Gate Structures for upstream and downstream

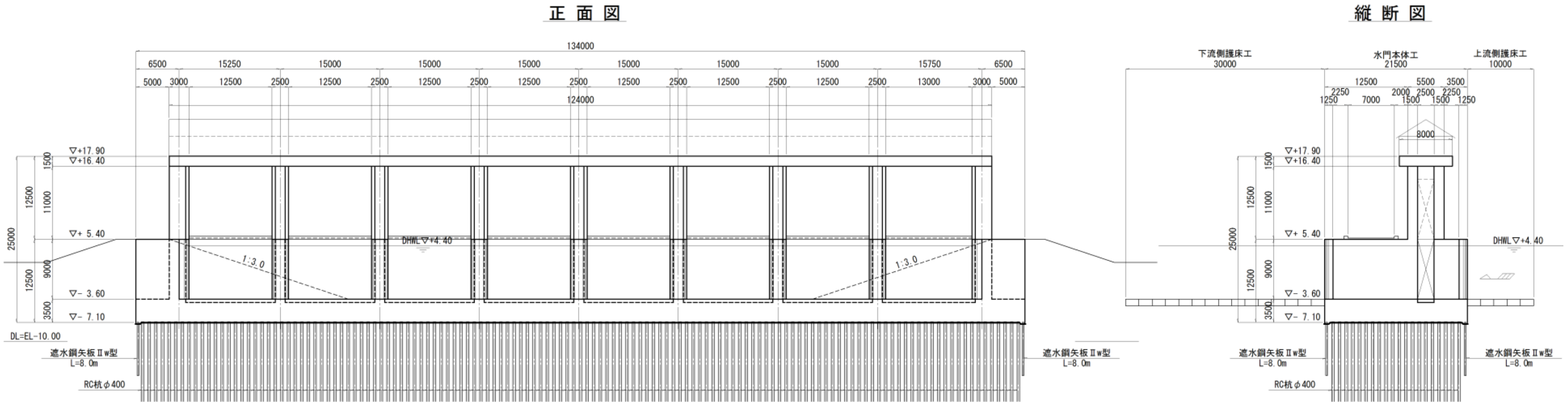
A split facility at the time of the flood is necessary at the diversion point of the Chao Phraya River (upstream end). The upstream diversion part method mainly includes a fixed weir type by natural overflow and an intake gate (Gate type) method. In the fixed weir type, although it is relatively inexpensive and there is an advantage that operation is unnecessary, it is impossible to adjust the inflow amount and inflow frequency to the water discharge channel. At the intake gate (Gate type), it is possible to adjust the inflow amount and inflow frequency to the water discharge channel. The river width of the flow dividing portion can be made smaller than that with the fixed weir type. Many achievements have been made in intake gate structures, including the King Rama VI barrage and the Chao Phraya River basin. For the above reasons, it is decided to adopt an intake gate (gate type) system. At the Diversion Channel, it is possible to carry out the planned drainage of water without installing a drain pump such as those in Suvarnabhumi airport drainage channel. On the other hand, considering the current flow situation, it is necessary to prevent salt water from running up into the Diversion Channel. For this purpose, the intake gate (gate type) shall be installed. In the event of flooding, the gate shall be opened fully to ensure flood drainage and shall have the function to prevent sea water intrusion during normal times. The intake gates at the upstream end and the downstream end (estuary) are shown Figure 2.4.13. Structural drawing of the gate that will be installed in the Diversion Channel is shown in Figure 2.4.14.

Gate at the entrance (upstream end) of Diversion Channel

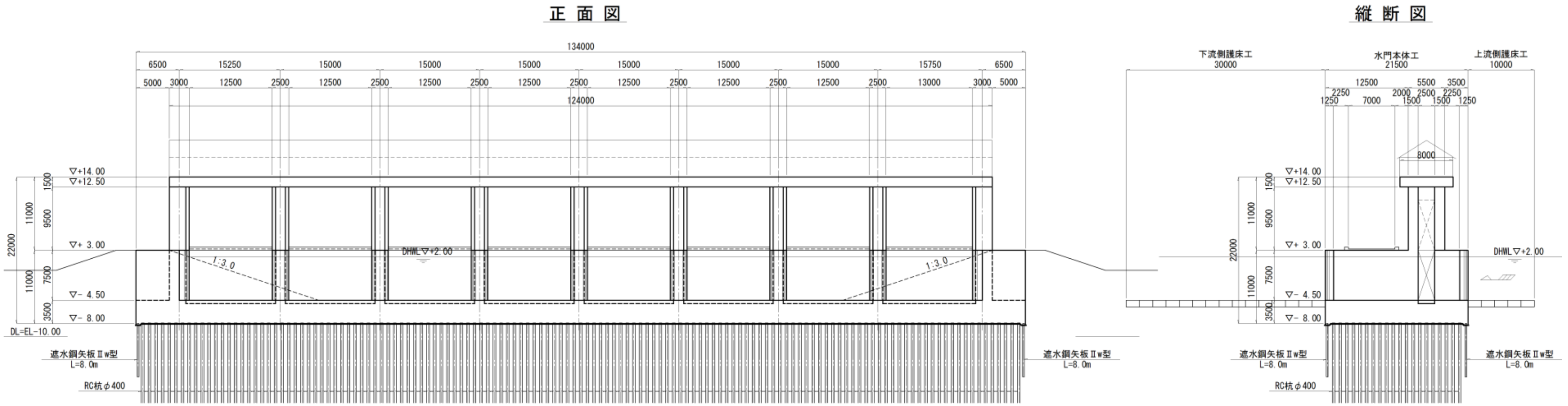
Gate at the outlet (downstream end) of Diversion Channel

Source: JICA Study Team

Figure 2.4.14 Intake gate at the diversion point (upstream)



Gate at the entrance (upstream end) of Diversion Channel



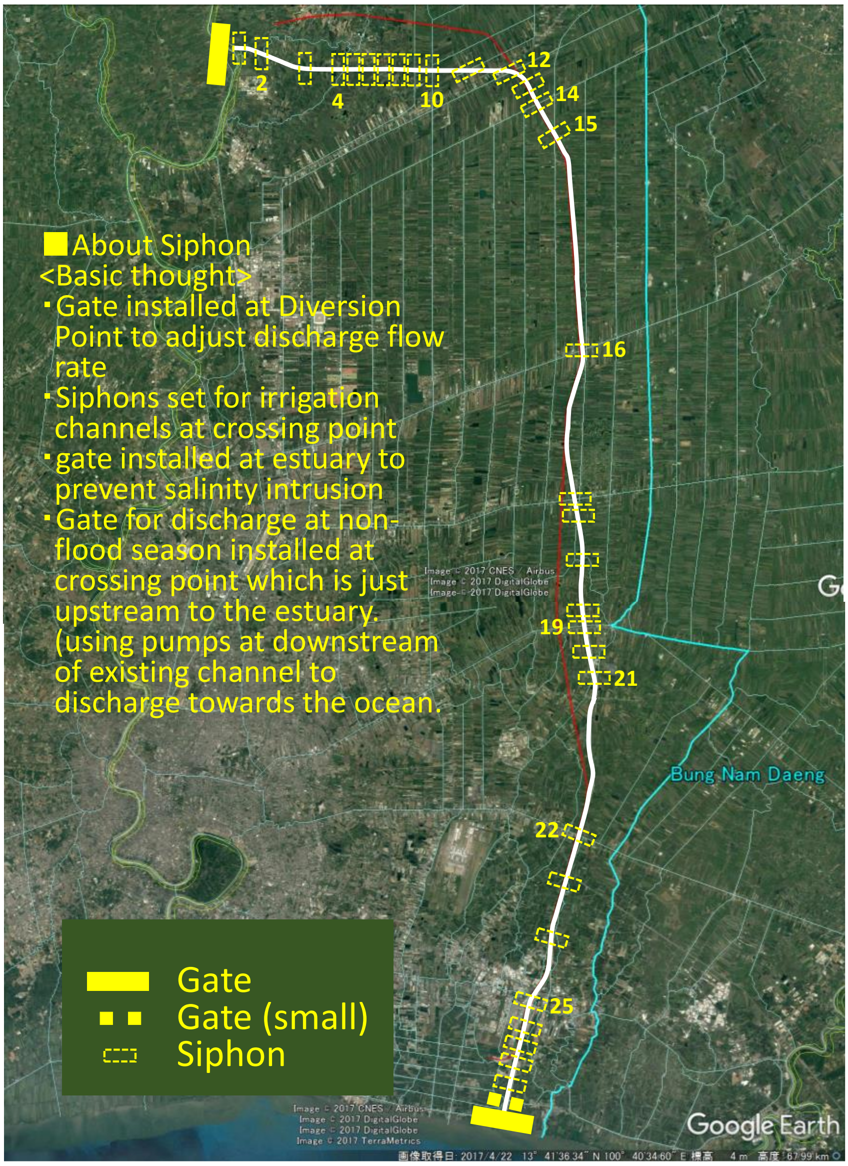
Gate at the outlet (downstream end) of Diversion Channel

Source: JICA Study Team

Figure 2.4.15 Structural Drawing of the Gate in the Diversion Channel

(3) Siphon Structure

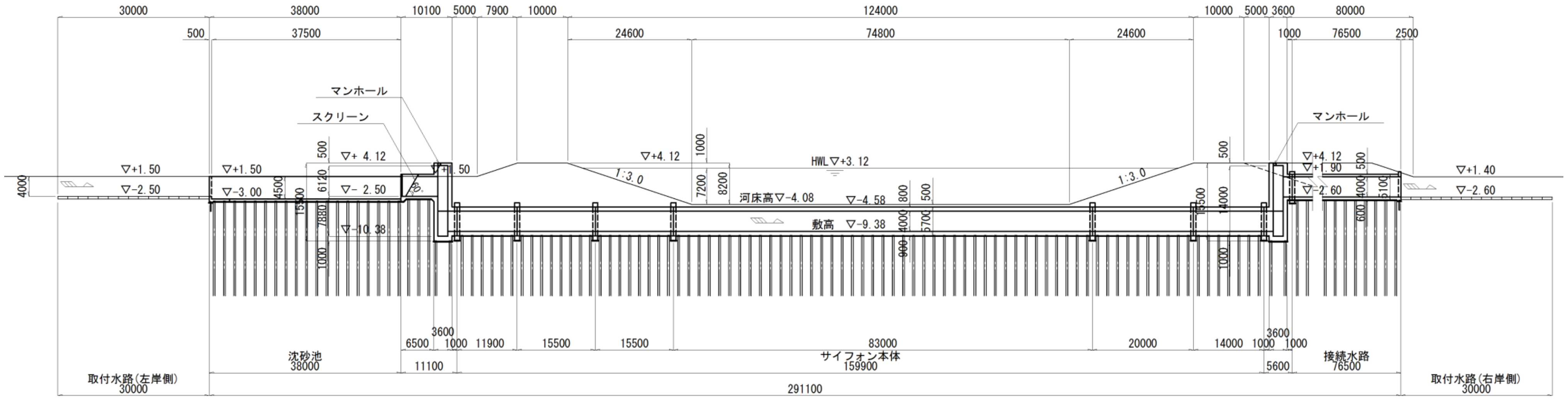
Since there are many irrigation channels running across the alignment of the Diversion Channel, those channels will be cut by the construction of the Diversion Channel. Therefore, siphon structure is considered, instead of linking them to the Diversion Channel, to avoid the cut-up as well as the impact of water level fluctuation on irrigation. By maintaining the flow capacity of the siphon, the channels can be kept functional in terms of irrigation and flood control. There is another option, installation of the gate structure for the crossing irrigation channels to maintain the function of existing irrigation channels instead of the siphon system. However, this option is not practically feasible, due to it is always necessary to keep the water level of the Diversion Channel lower than the water level of the irrigation channels in order to maintain the drainage function of the irrigation channels.



■About Siphon
<Basic thought>
- Gate installed at Diversion Point to adjust discharge flow rate
- Siphons set for irrigation channels at crossing point
- gate installed at estuary to prevent salinity intrusion
- Gate for discharge at non-flood season installed at crossing point which is just upstream to the estuary. (using pumps at downstream of existing channel to discharge towards the ocean.

Source: JICA Study Team

Figure 2.4.16 Location plan of siphons



Source: JICA Study Team

Figure 2.4.17 Crosse section of siphon

2.4.3 The Outer Ring Road

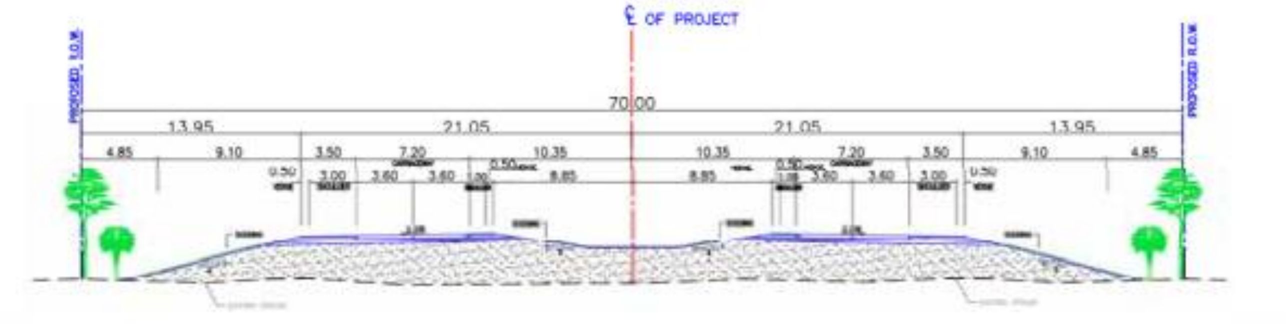
The Outer Ring Road was planned by the Department of Highways (DOH), Ministry of Transport (MOT), after the completion of the 1st and 2nd Outer Ring Road. The location is outside of the 2nd Outer Ring Road, as a toll road, in order to solve the problem of traffic congestion in the capital city, and the design speed is 120 km/hour. Feasibility study of this road was conducted during October 2006 to December 2007. Although the basic design of 6 or 4 lanes main road with or without service roads by concrete pavement will not be changed, the following points are proposed, when considering the integration of the project with the Diversion Channel.

1. Excavated soil (Bangkok clay) from the Diversion Channel shall be utilized for embankment of the Outer Ring Road at about 60 km out of total 97.112 km of the road, by mixing the clay and sand.
2. The stockpile of mixing materials from the above will work as a pre-loading for the road embankment in order to reduce the differential settlement and accelerate the consolidation.
3. Where the soft clay layer in the ground is very thick, for around 13 km at the south part of the eastern section, the elevated road structure shall be recommended.

The reason of these amendments is stated in "Supporting Report Section 6: Review of Structure of the Outer Ring Road".

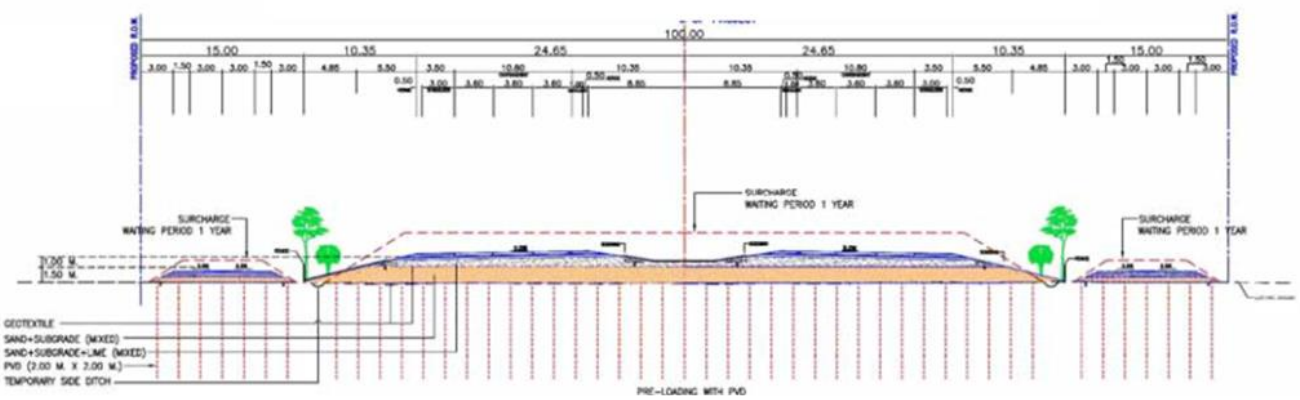
(1) Typical Cross Section of the Main Road

The typical cross sections of the Outer Ring Road are shown below.



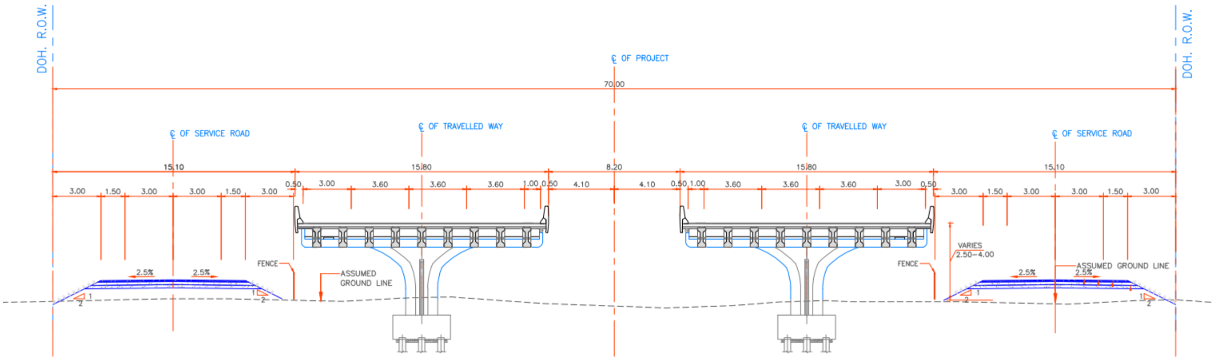
Source : JICA Study Team based on DOH FS 2009

Figure 2.4.18 The Outer Ring Road (East section, north part), 4 lanes without service roads



Source : JICA Study Team based on DOH FS 2009

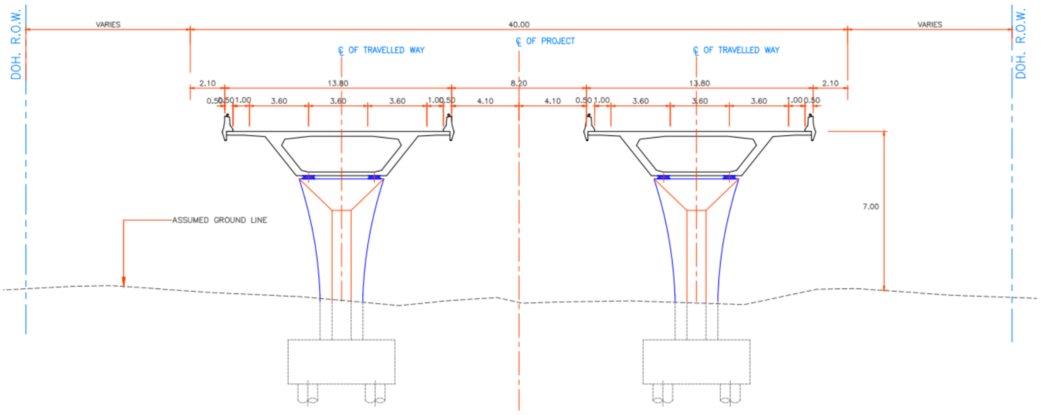
Figure 2.4.19 The Outer Ring Road (East section, central part), 6 lanes with PVD methods



TYPICAL SECTION ②

MAIN ROAD AND SERVICE ROAD TYPICAL SECTION

STA. 88+800 TO STA. 95+600 EAST LINE



TYPICAL SECTION ③

STA.96+560 – STA.97+112

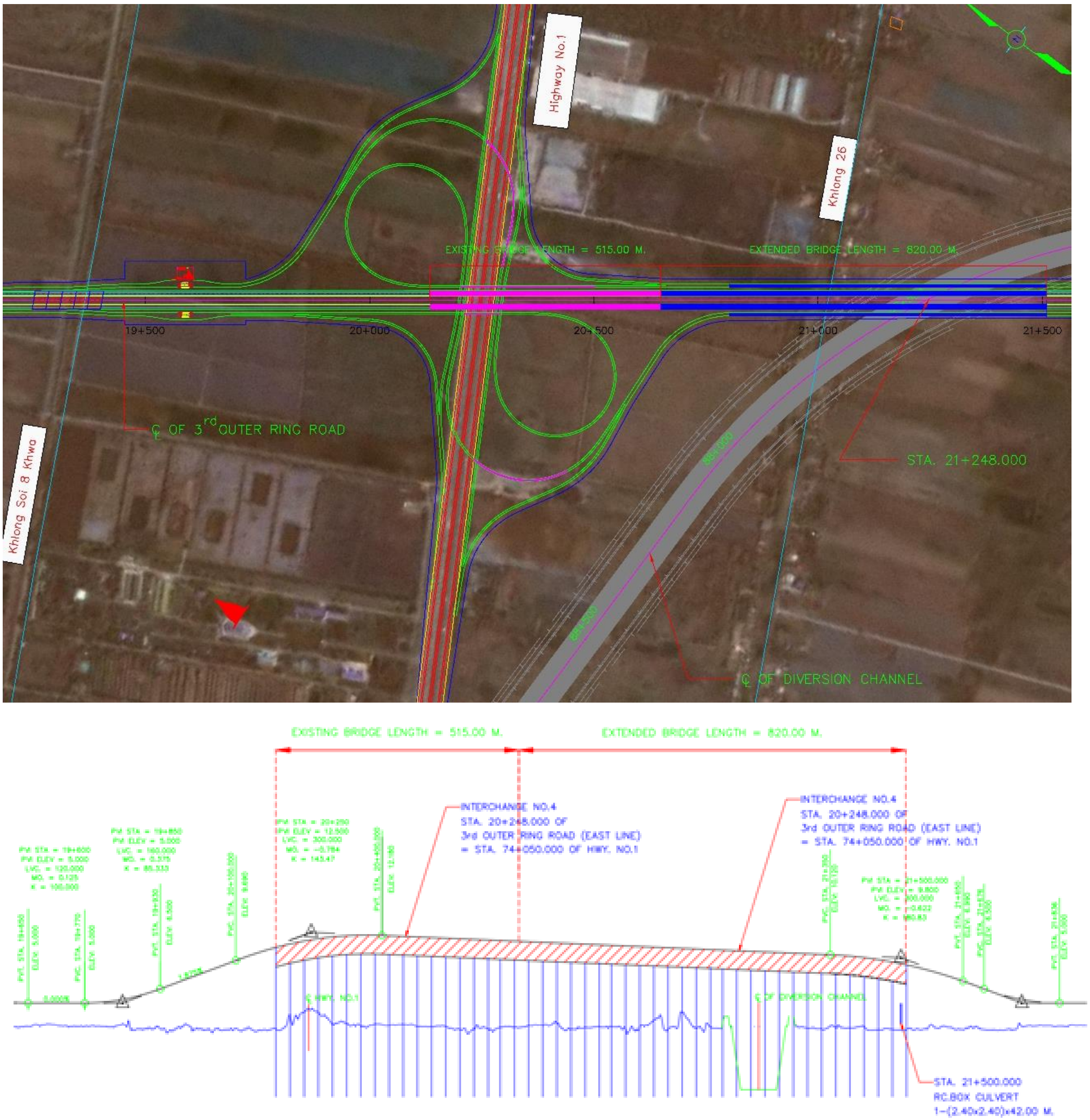
Source : JICA Study Team based on DOH FS 2009

Figure 2.4.20 The Outer Ring Road (East section, elevated part), 6 lanes, viaduct

(2) Other Structures

In the case of "Integrated Project", the following auxiliary structures shall be changed.

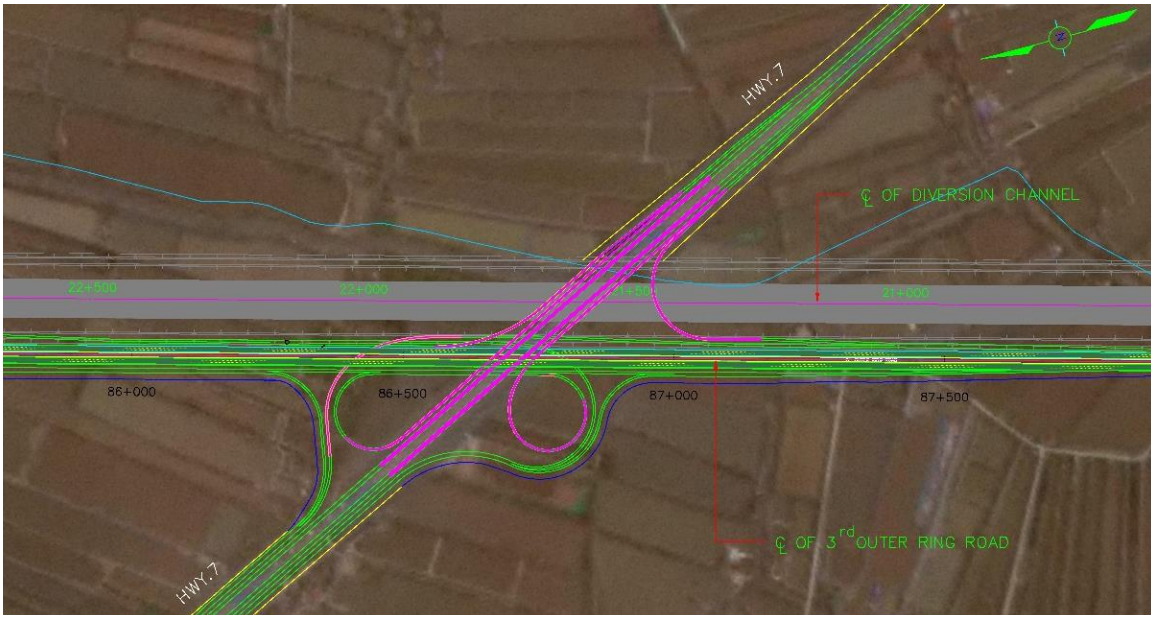
i. For crossing the Diversion Channel, a new bridge with length of around 820 meters will be necessary for the Outer Ring Road near the IC-4, as shown in Figure 2.4.20.



Source: JICA Study Team

Figure 2.4.21 A bridge for the Outer Ring Road crossing with the Diversion Channel near IC-4 (STA20+248)

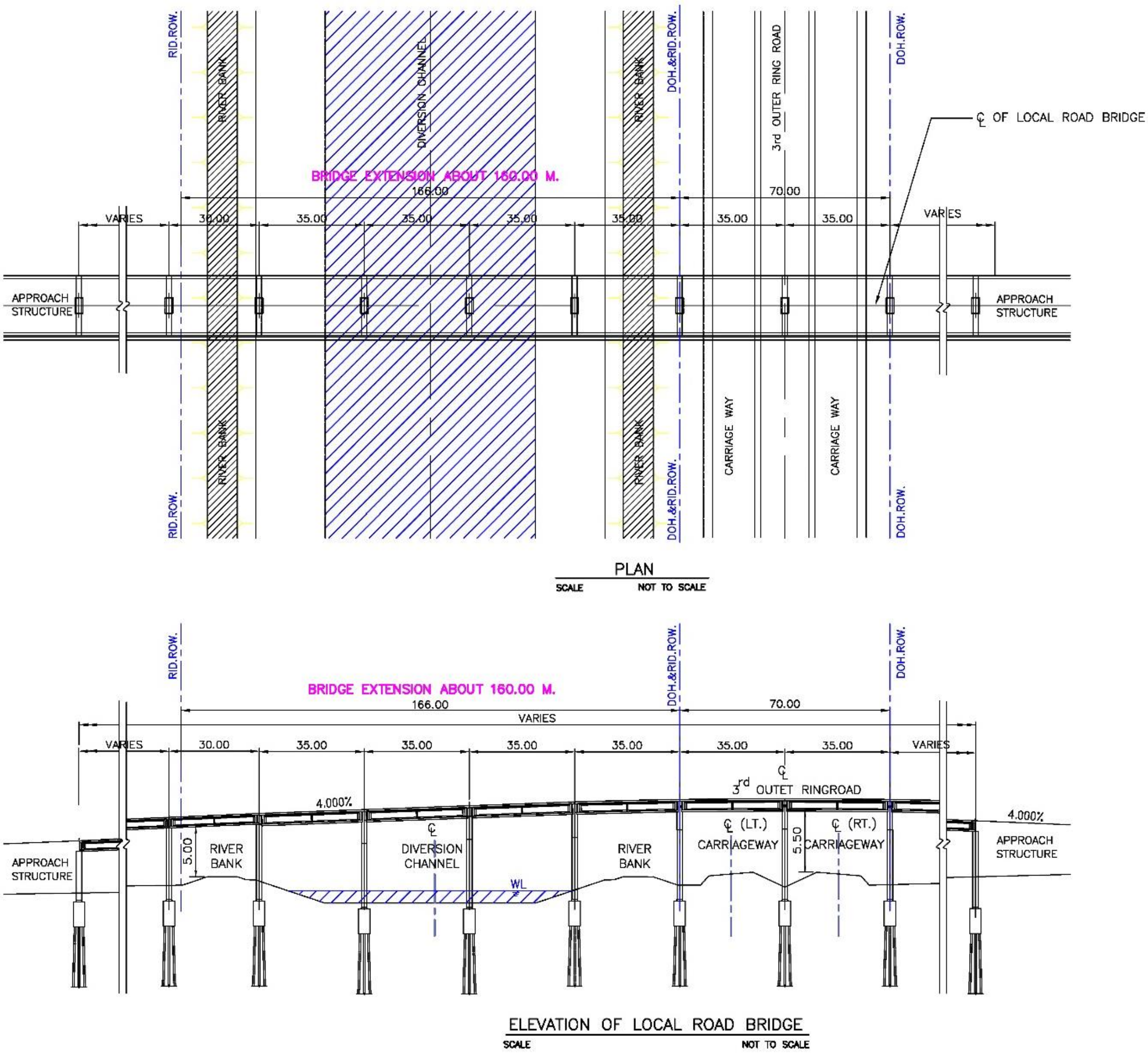
ii. The plans of 4 interchanges (IC-5, IC-9, IC-10, IC-11) shall be modified because the Diversion Channel is connected parallel with the Outer Ring Road. Therefore some modification would be made because of changes of length of ramps or ramp bridges for crossing the Diversion Channel. Figure 2.4.22 shows one example, layout of IC-10, where the Outer Ring Road have a junction with Highway No.7 (Bangkok - Chonburi Road).



Source: JICA Study Team

Figure 2.4.22 The Outer Ring Road (East section), example of the amended interchange plan (IC-10)

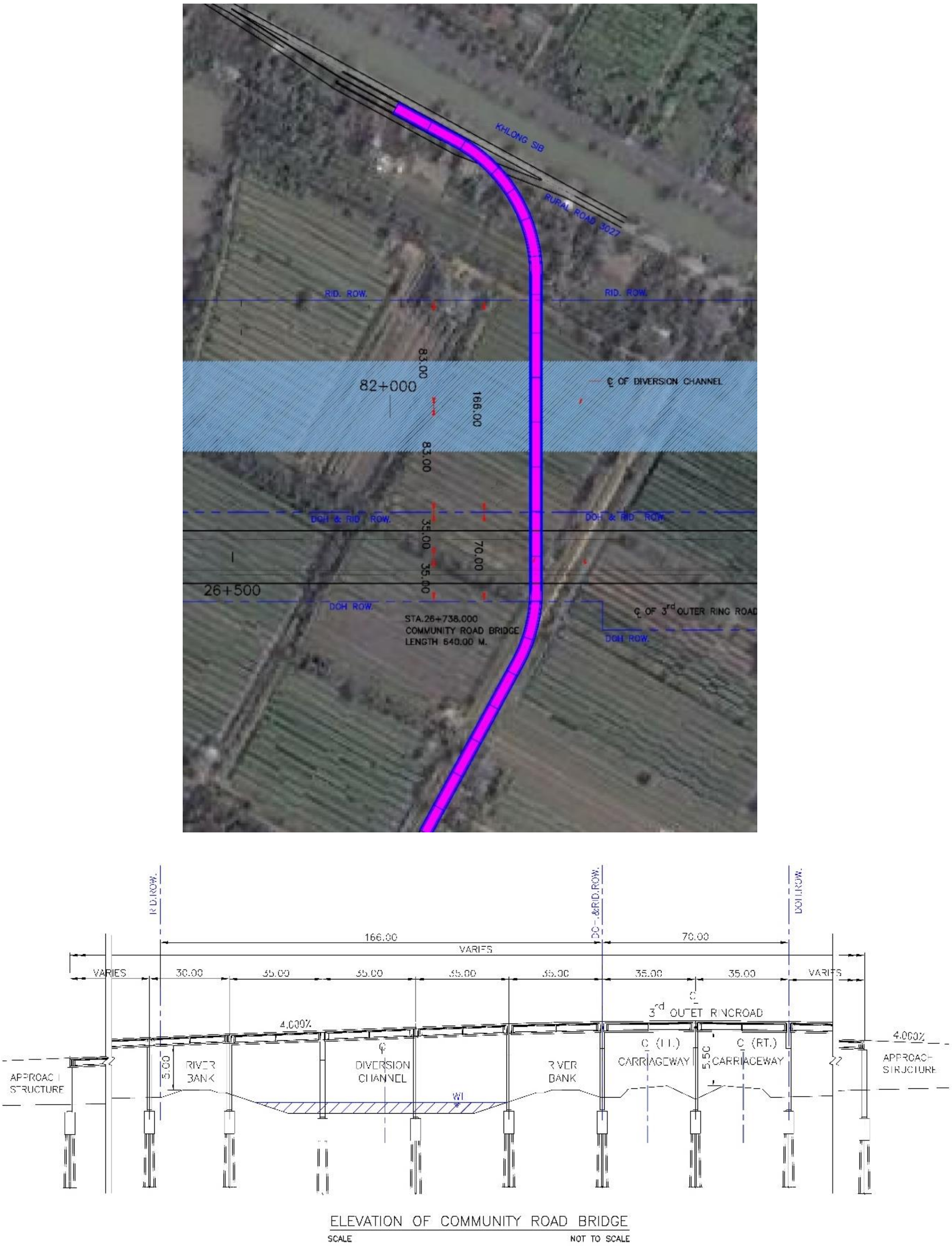
iii. The bridge length of the existing local road overpassing the Outer Ring Road shall be extended by 160 m from 400m which was proposed by FS by DOH, where the bridge has to overpass the Diversion Channel. General plan and cross section of such bridge is shown in the following figure.



Source : JICA Study Team

Figure 2.4.23 The Outer Ring Road (East section), typical plan and profile of the local existing road bridge overpassing the Outer Ring Road together with the Diversion Channel.

iv. Divided communities by the Outer Ring Road was previously planned to be connected by an underpass. However, an overpass bridge shall be where the Diversion Channel is connected parallel with the Outer Ring Road. Following figure shows typical plan and profile of such bridge.



Source : JICA Study Team

Figure 2.4.24 The Outer Ring Road (East section), typical plan and profile of the community road bridge overpassing the Outer Ring Road and the Diversion Channel

CHAPTER3 IMPLEMENTATION PLAN

3.1 Procurement and Construction plan

3.1.1 Principal work quantity

Principal work quantities of Outer Ring Road Diversion Channel is shown in the Table 3.1.1. These values are the quantities per Unit (500m long) that is necessary to set for the estimation of required days in each construction step.

Table 3.1.1 Principal work quantities (Outer Ring Road Diversion Channel)

Work Items			Unit	Northern Part	Central Part	Southern Part
(1) Removal Existing Facilities			Not counted in this study			
(2) Reclamation / Laying Construction Road			m^3/500m	0	0	100,000
(3) Changing Route of Existing Channel			Not counted in this study			
(4) Soil Stabilization	PVD	Sandmat	m^3/500m	0	36,700	31,600
		PVD	m^3/500m	0	249,200	949,800
	SCC		Column/500m	0	9,900	22,200
(5) Excavation	Total	Laying construction road	m^3/500m	28,650		
		Excavation	m^3/500m	264,000		
		Soil disposal	m^3/500m	226,000	140,100	180,000
	Excavation (depth 0-3m) (Dry season)	*Laying construction road*	*m^3/500m*	*19,850*		
		Excavation	*m^3/500m*	*145,500*		
		Soil disposal	*m^3/500m*	*107,500*	*21,600*	*61,500*
	Excavation (depth 3-6m) (Rainy season)	*Laying construction road*	*m^3/500m*	*8,800*		
		Excavation	*m^3/500m*	*118,500*		
		Soil disposal	*m^3/500m*	*118,500*	*118,500*	*118,500*
(6) Temporary Placing			m^3/500m	185,800	185,800	185,800
(7) Preparing Stock Pile / Pre-Loading	Channel		m^3/500m	57,000	62,600	90,200
	Road		m^3/500m	61,700	123,200	35,900
(8) Plant Mixing			m^3	14,824,000		
(9) Embanking	Channel	Embankment	m^3/500m	57,000	62,600	90,200
		Embankment utilizing excavated soil	m^3/500m	57,000	62,600	90,200
		Clay (Excavated soil)	m^3/500m	38,000	41,800	60,100
		Sand	m^3/500m	19,000	20,800	30,100
	Road	Embankment	m^3/500m	61,700	123,200	35,900
		Embankment utilizing excavated soil	m^3/500m	0	123,200	35,900
		Clay (Excavated soil)	m^3/500m	0	82,100	23,900
		Sand	m^3/500m	0	41,100	12,000

Source : JICA Study Team

3.1.2 Shift and worktime

In the study on construction plan for the Outer Ring Road Diversion Channel, the following conditions were supposed.

- Principally, the working time per day is seven hours.
- Construction work is carried out in the day time only.

3.1.3 Workable days

The number of workable days calculated from daily precipitation (2000 to 2009) observed in Bangkok by Thai Meteorological Department's is as shown in Table 3.1.2. According to the calculation method in Japan, workable days will be 185 days per year, 123 days in dry seasons, 62 days in rainy season. However, due to the large scale of combined construction of the Outer Ring Road and the Diversion Channel, in consideration of the following, the number of workable days in the dry season should be 150 days, and the number of workable days in the rainy season should be 75 days.

- In order to complete within the assumed construction period, it is necessary to increase the number of construction days per year more than usual
- It is also possible to increase the working time per day which is usually seven hours for construction planning

Table 3.1.2 Workable days

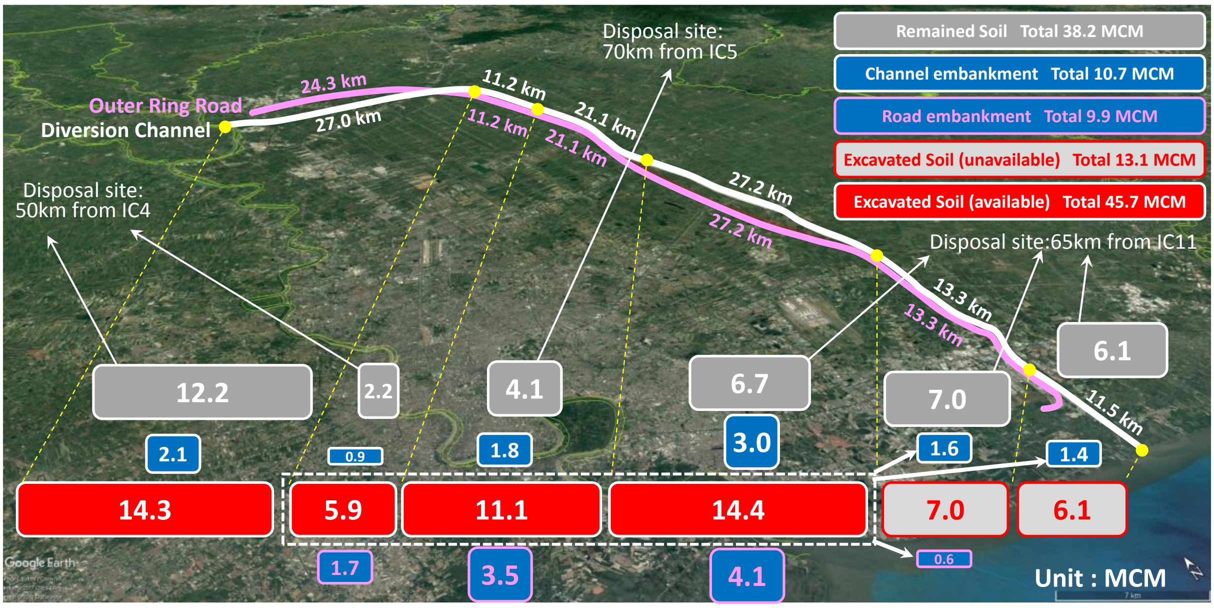
Items		May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
1) Days		30	31	31	31	30	31	30	31	31	28	31	30	365
2) Sunday and National Holiday		7	4	8	6	4	8	4	7	6	6	4	9	73
3) Machine maitenance		1	1	1	1	1	1	1	1	1	1	1	1	12
4) Unworkable rainy days		14	12	11	12	15	15	3	1	1	2	3	6	95
5) Total unworkable days	2)+3)+4)	22	17	20	19	20	24	8	9	8	9	8	16	180
6) Workable days	1)-5)	8	14	11	12	10	7	22	22	23	19	23	14	185
		62						123						
		↓						↓						Unit : days
		Workable days in rainy season 75						Workable days in dry season 150						

Refer to Daily rainfall observed by TMD at Bangkok from 2000 to 2009.
Unworkable days depends on weather condition : If daily rainfall is 5mm/day or more, this day is unworkable. Number of unworkable days are as below depend on daily rainfall.
Daily rainfall is 5 mm/d or more, and less than 20 mm/d : 1 day
Daily rainfall is 20 mm/d or more, and less than 35 mm/d : 2 days
Daily rainfall is 35 mm/d or more, and less than 65 mm/d : 3 days
Daily rainfall is 65 mm/d or more, and less than 100 mm/d : 4 days
Daily rainfall is 100 mm/d or more, and less than 170 mm/d : 5 days
Daily rainfall is 170 mm/d or more : 6 days

Source : JICA Study Team

3.1.4 Soil volume balance

The clay excavated from the Diversion Channel shall be used as a material for the embankment of the road and the embankment of the channel. The amount of excavated soil, the amount of soil used as a material of the embankment of the road and the embankment of the channel, and the amount of the remained soil are shown in Figure 3.1.1. Excavated clay from the channel cannot be used as it is for the embankment material, but shall be mixed with sand. The sand for mixing is brought to the construction site by being purchased and transported.



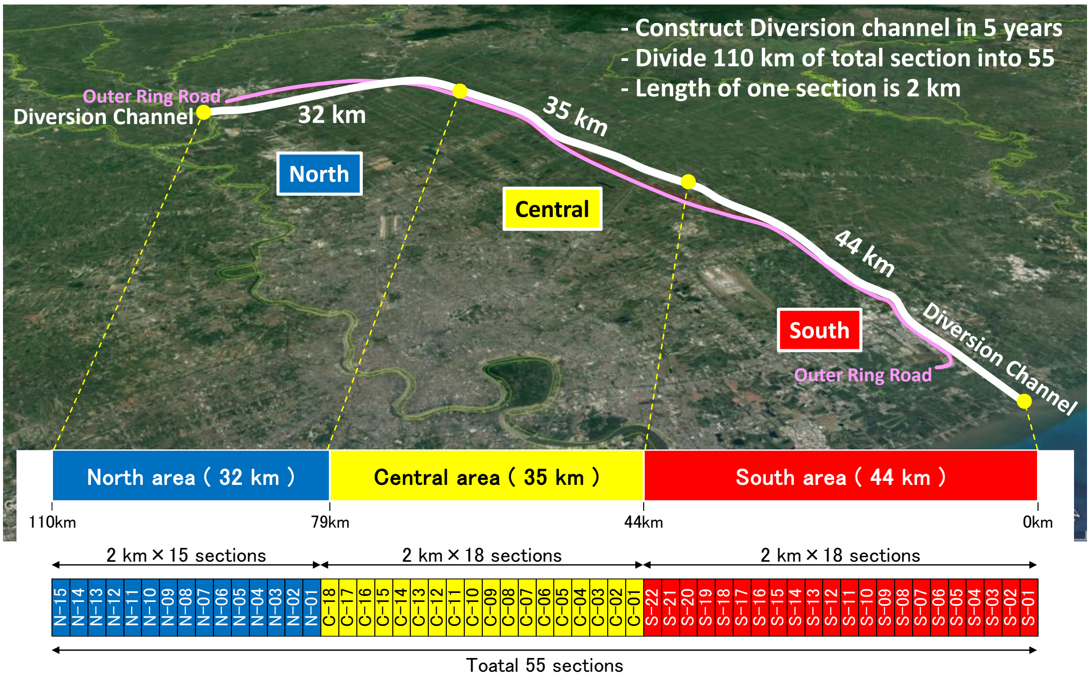
Source : JICA Study Team

Figure 3.1.1 Soil volume balance of Outer Ring Road and Diversion Channel combined construction

Figure 3.1.1 shows the excavated soil volume of Diversion Channel, the amount of soil for embankment usage, and the amount of soil remaining in each section. For example, in the second section from the north side (length of 11.2 km), 5.9 MCM of soil will be excavated to construct the Diversion Channel, 0.9 MCM will be used as a material to construct channel embankment, 1.7 MCM will be used as a material for road embankment, and 2.2 MCM will be treated as surplus soil. In the two sections on the south side, water content of the excavated soil is high, so these soil cannot be used as a material for embankment. Therefore, the whole amount is disposed off as a remained soil.

3.1.5 Construction period and section division

Construction period of the combined project of the Outer Ring Road and Diversion Channel is assumed to be 5 years considering the previous plan of the Outer Ring Road. In order to finish the construction in time, every 2km is defined as one section and construction (excavation and embankment) shall be executed simultaneously in 55 sections. Section amount will be too many if the section distance is less than 2 km, while it will be impossible to complete the construction in 5 years if the section distance is larger.

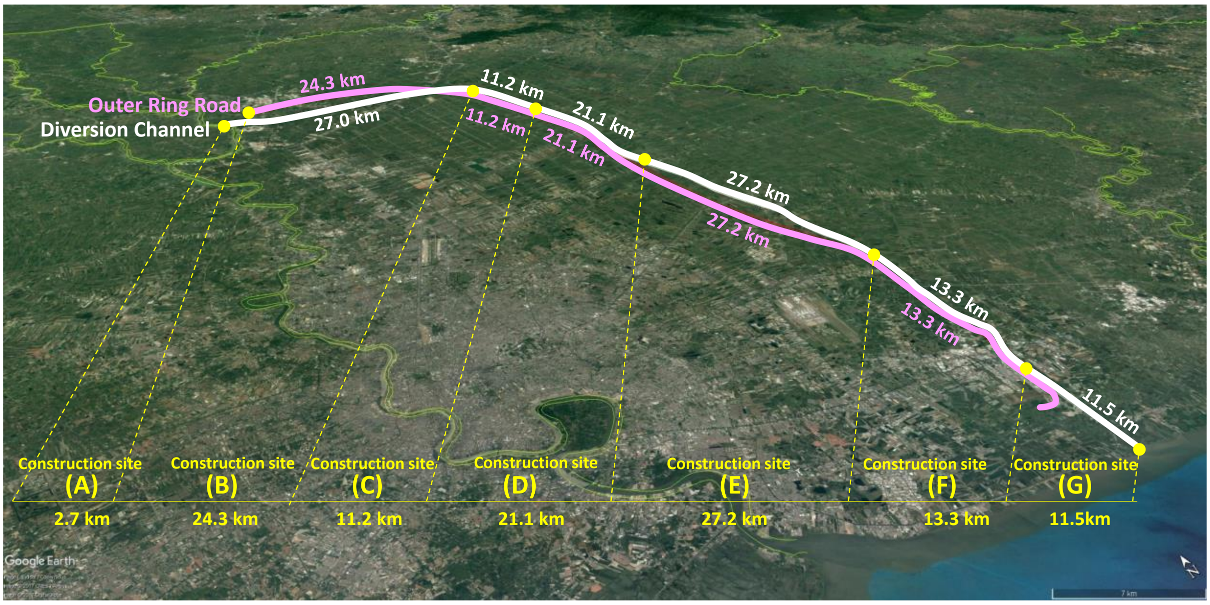


Source : JICA Study Team

Figure 3.1.2 Section division

3.1.6 Construction site

Due to the long distance of the Outer Ring Road and Diversion Channel, seven construction site are identified (A to G). These sites are related to construction supervision and mobilization during the construction period.



Source : JICA Study Team

Figure 3.1.3 Construction site

3.1.7 Construction steps

Construction steps of the combined project are shown in following figure. For construction site A ~ E, only road construction of step (2) is needed while wet land reclamation can be omitted since they are not wet lands. As the result of slope stability analysis, soil stabilization, step (4) in the figure, is unnecessary for site A and B because the safety factor of the excavated slope is over 1.3 and both residual and final subsidence are lower than the allowable limit. Also, step (8) can be omitted for these two sites because the soil for the embankment will be newly purchased.

	Construction Site		
	(A)-(B)	(C)-(E)	(F)-(G)
(1) Removal Existing Facilities	●	●	●
(2) Reclamation / Laying Construction Road	▲	▲	●
(3) Changing Route of Existing Channel	●	●	●
(4) Soil Stabilization	---	●	●
(5) Excavation	●	●	●
(6) Temporary Placing	●	●	●
(7) Preparing stock pile / Pre-Loading	●	●	●
(8) Plant Mixing	---	●	---
(9) Embanking	●	●	●

Legend

●: Implement in this site
▲: Implement part of this work
---: Not necessary in this site

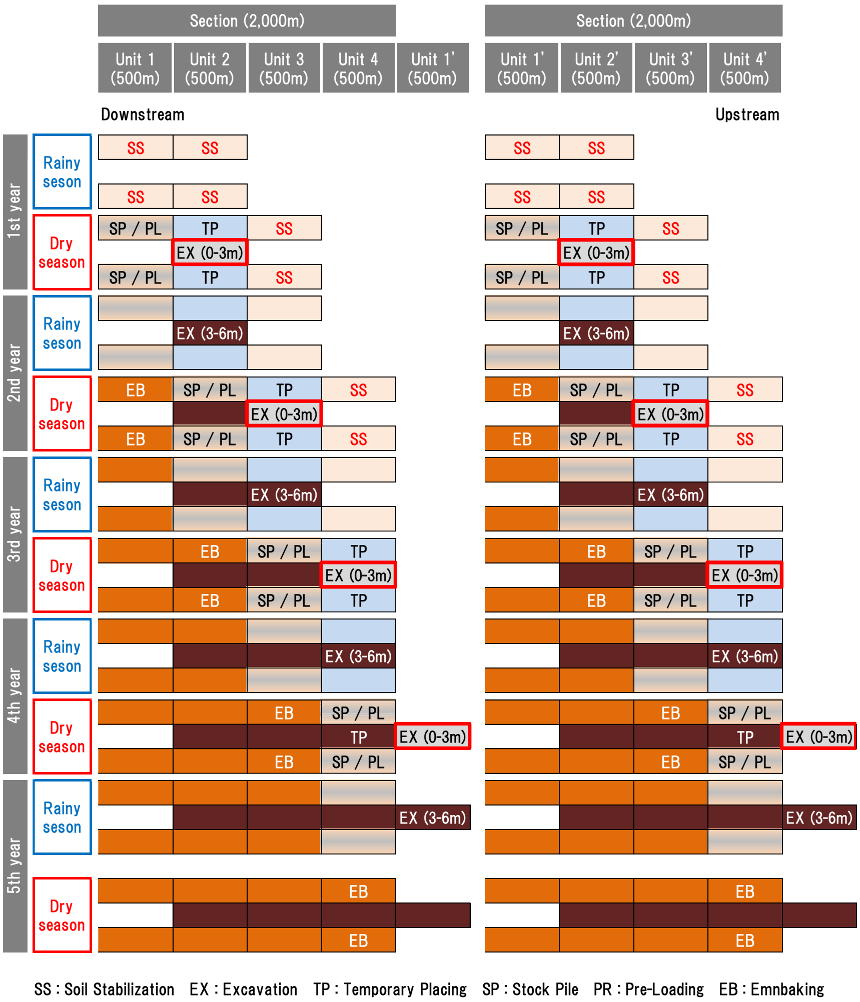
Source : JICA Study Team

Figure 3.1.4 Construction steps

3.1.8 Construction method in sections

(1) Construction process during a 5-year period

An example of the construction process is explained for a construction site D during a 5-year period. Construction period for the whole project is assumed to be 5 years as given in previous F/S by DOH, therefore, in this study, the construction period of the Outer Ring Road and Diversion Channel is set to 5 years. In order to complete the construction in 5 years, the length of one section is set to be of 2 km, and excavation and embankment work are carried out simultaneously in 55 sections. Figure 3.1.5 indicates the construction process of two sections next to each other. During the rainy season of the 1st year, soil stabilization should be carried out at the downstream, for two units. During the dry season of the 1st year, excavation of the channel (3 m in depth from the ground level) at the second unit from downstream should be carried out. At the same time, temporary placing of excavated clay and purchased sand, and preparing stock pile should be carried out. During the rainy season of the 2nd year, excavation of the channel (from 3 m to 6 m in depth) should be carried out at the same area excavated in the dry season of the 1st year. Excavated clay from the depth between 3 m to 6 m should be disposed because the water content of this clay is very high and is not suitable as material for the embankment. During the dry season of the 2nd year, at the 3rd section from downstream, excavation of the channel should be carried out, and at the same time, the embankment at the most downstream section should be carried out. In the same way, if this construction work is carried out until the dry season of the 5th year, excavation and embankment in the 2-km section will be completed.

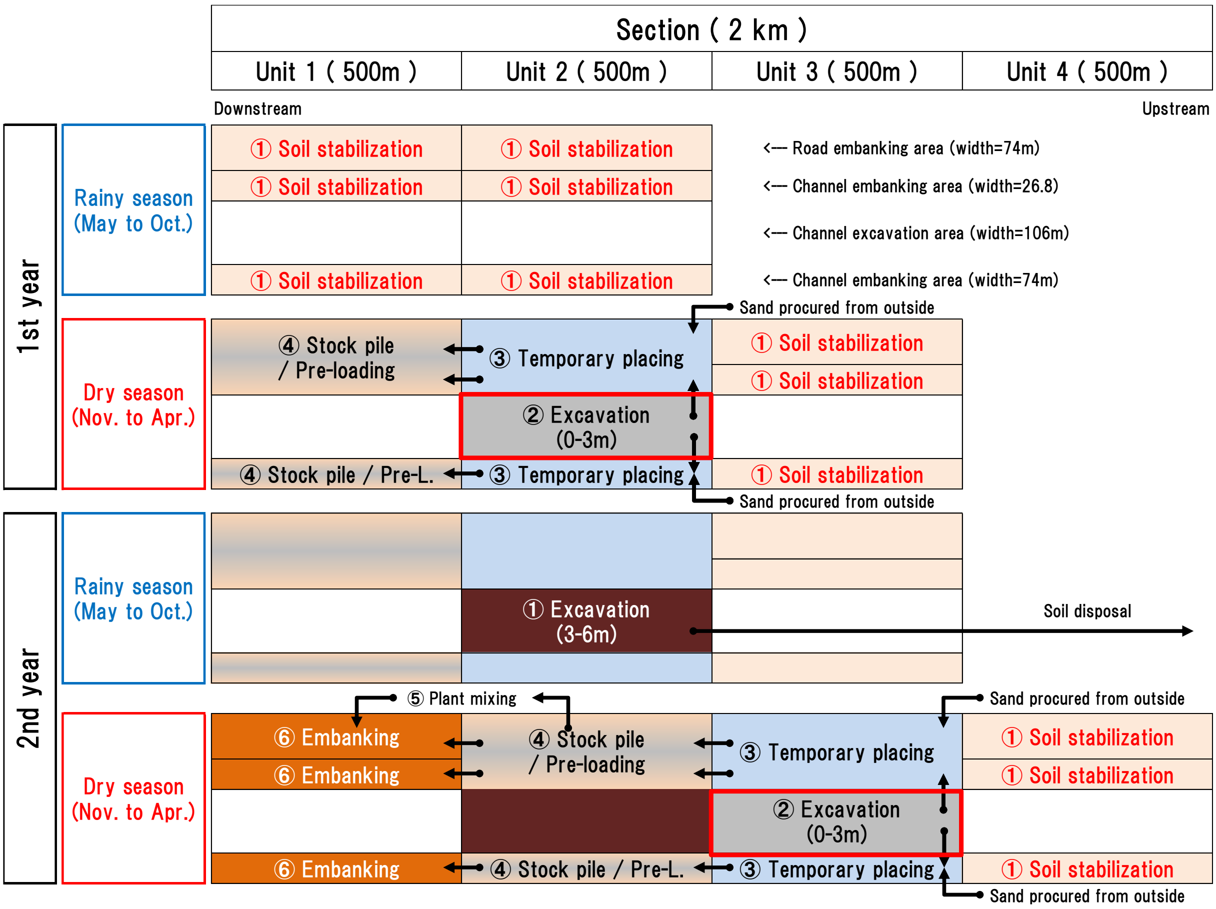


Source : JICA Study Team

Figure 3.1.5 Road and Channel combined construction process in the two consecutive sections during 5 years period

(2) Construction process during the first 2 years

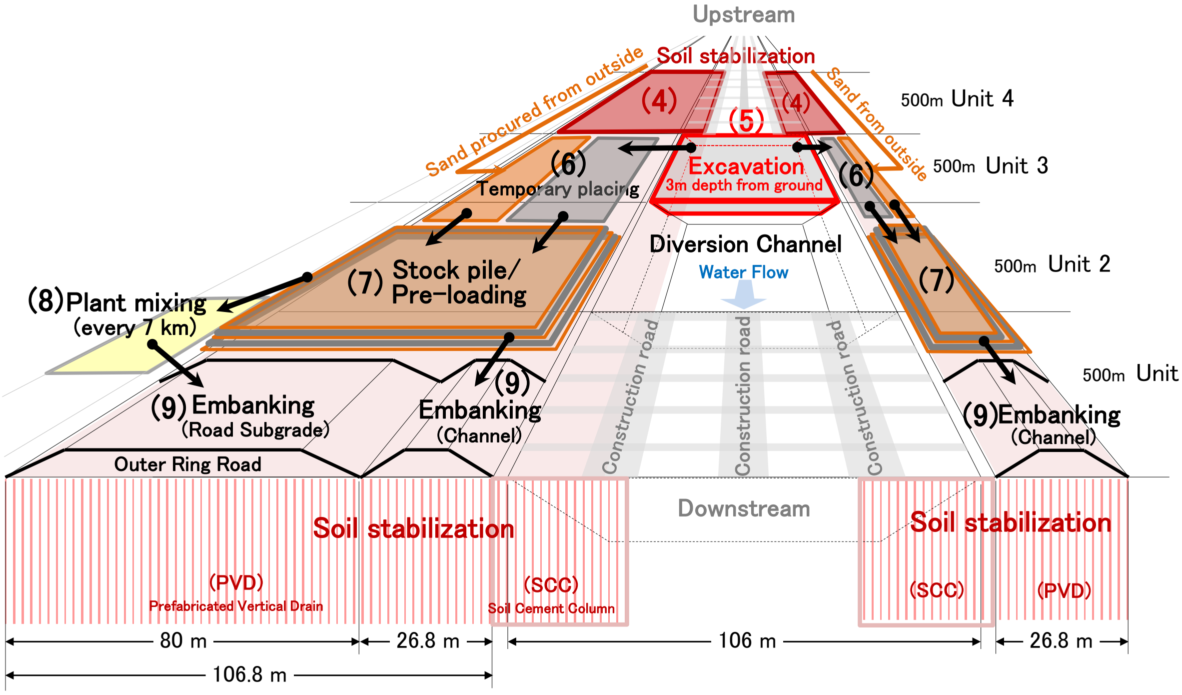
Taking construction site D as an example, here is a brief instruction of the construction steps for the first 2 years. The construction process in the first 2 years of the total 5-year construction period, demonstrated in one section, is shown in Figure 3.1.6. Excavation and embankment construction shall be carried out from downstream towards upstream within the respective section. During the rainy season of the 1st year, soil stabilization shall be carried out in two downstream units. During the dry season of the 1st year, further upstream soil stabilization, excavation from the ground to 3 m in depth, temporary placing of excavated soil, and preparing stockpile shall be carried out. The prepared stockpile is kept as it is for a year and it functions as pre-loading in the site (embankment area). During the rainy season of the 2nd year, excavation shall be performed at a depth of 3 m to 6 m. Soil generated by this excavation is disposed as a remained soil. During the dry season of the 2nd year, construction shall be carried out in the same way as during the dry season of the 1st year, and embankment of the most downstream unit shall be carried out. By this time, for the embankment of the Diversion Channel, clay and sand shall be mixed up by cutting off the prepared stockpile. Regarding the road embanking, after cutting off the stockpile, the mixed soil shall be further mixed in a mixing plant used for road embankment. Although the above method is generally assumed, but depending on circumstances, Levels-1 to 4 (as mentioned above) shall be appropriately utilized case by case.



Source : JICA Study Team

Figure 3.1.6 Road and Channel combined construction process in one Section during first 2 years

Details of the construction process in one section from (4) Soil Stabilization to (9) Embanking in the dry season of the 2nd year are as shown in Figure 3.1.7.



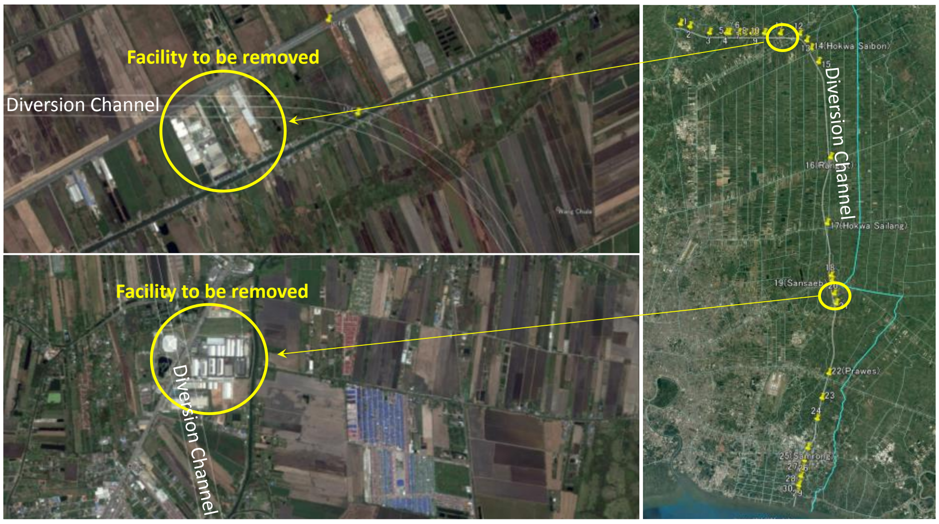
Source : JICA Study Team

Figure 3.1.7 Construction process in one Section during dry season in the 2nd year

3.1.9 Construction contents in each steps

(1) Removal of the existing facilities

The existing facilities in construction sites will be removed. It is assumed that removal of existing facilities can be completed during the rainy season of the 1st year. However, a further detailed survey of the existing facilities' condition and the duration for their removal is needed.

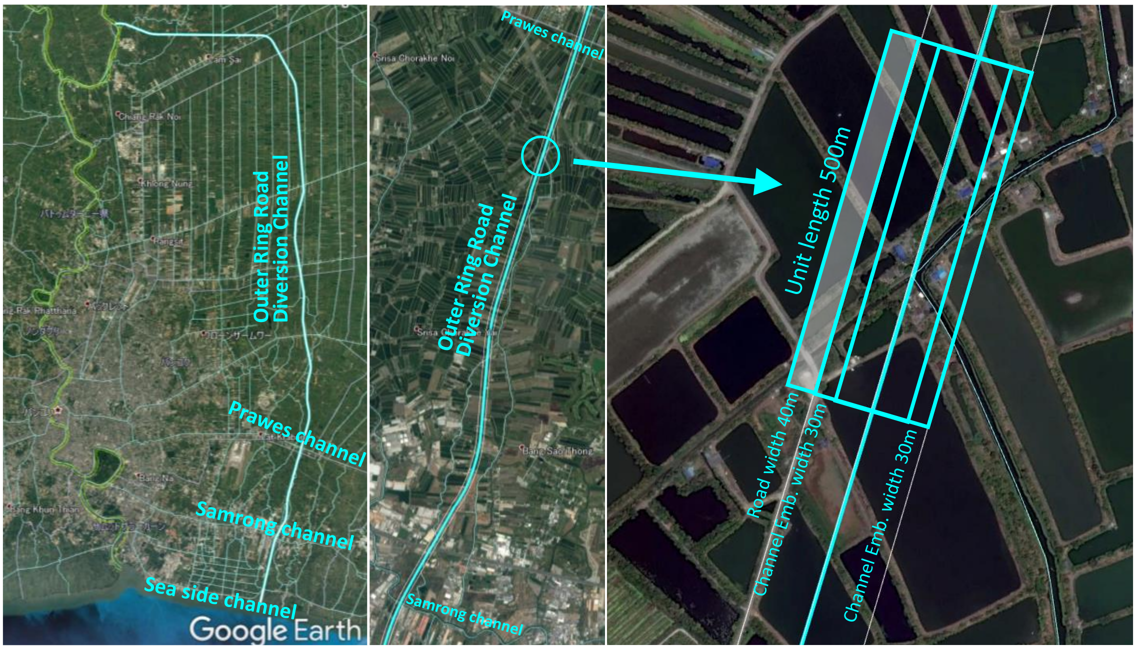


Source : JICA Study Team

Figure 3.1.8 Removal of the existing facilities

(2) Reclamation / Laying construction Road

The downstream of the “Prawes Channel” (23 km from the estuary) is currently used as paddy field, farm pond, and etc. Before the excavation of the Diversion Channel, these ponds shall be dried by reclamation or pumping. Construction steps are shown as follows. Both sides of the channel bank in the unit will be built with a reclamation soil. Reclamation on left bank will be 30m wide in order to build a dike of the Diversion Channel, while on the right bank, the reclamation will be 70-m wide for the construction of the dike and road. The reclamation will also be applied to both upstream and downstream unit, then existing irrigation canals will be linked in order to dry the excavation site.



Source : JICA Study Team

Figure 3.1.9 Wetland reclamation in the south part of the Diversion Channel

(3) Changing route of the existing channel

In order to keep the existing canals functional, transition work will be done in the area where the Diversion Channel runs across these canals. Meanwhile, siphon will be built to maintain these canals working after the construction of the Diversion Channel. The transition is projected to be finished during the dry season of the 1st year. As a reference, changing of the route of the existing channel is shown during the construction of Suvarnabhumi Airport Drainage Channel (Figure 3.1.10)

Source : JICA Study Team

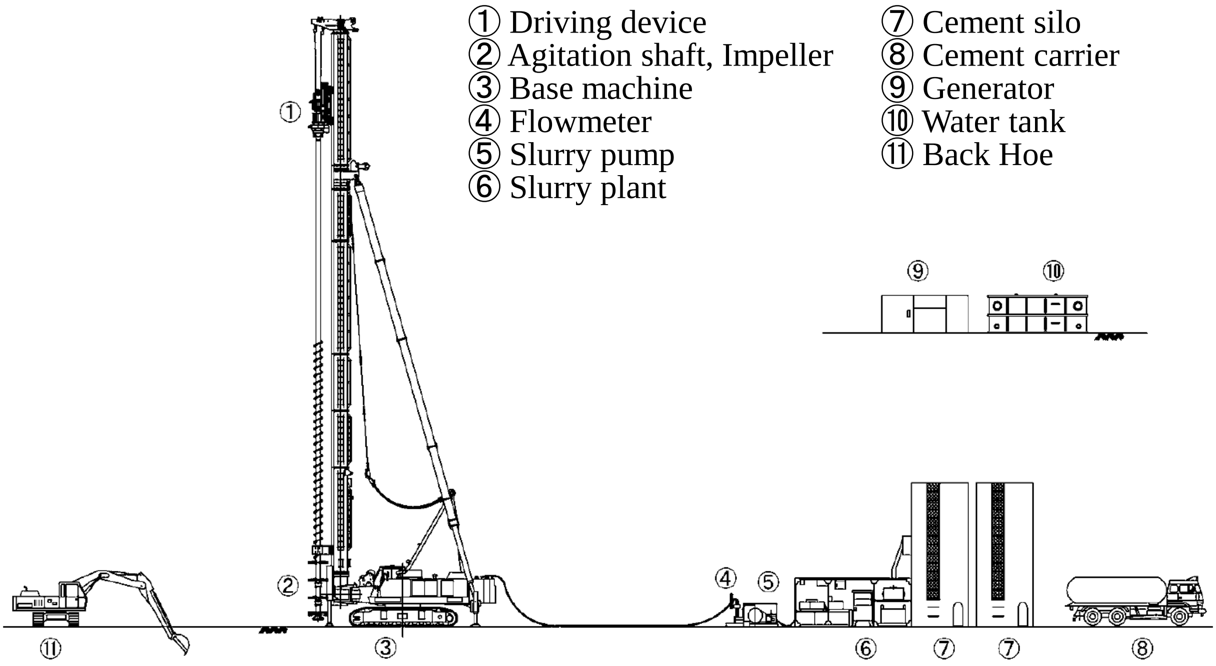
Figure 3.1.10 Situation of laying construction road during the Suvarnabhumi Airport Drainage Channel construction

(4) Soil Stabilization

Soil stabilization process shown below will be applied to the central part and the southern part. Soil Cement Column (SCC) will be applied to the slope of the bank on both sides of the Diversion Channel. For the embankment of dike and road, Prefabricated Vertical Drain (PVD) method is used to prevent the subsidence.

7) Soil Cement Column (SCC)

Standard machines plant layout for the installation of Soil Cement Column (SCC) is shown in Figure 3.1.11. Before installing SCC with base machine, it is necessary to install slurry pump, cement silo and other devices. These preparations shall be conducted before installing SCC so that the SCC work will not be impeded.



Source : JICA Study Team

Figure 3.1.11 Standard machines plant layout for the installation of Soil Cement Column (SCC)

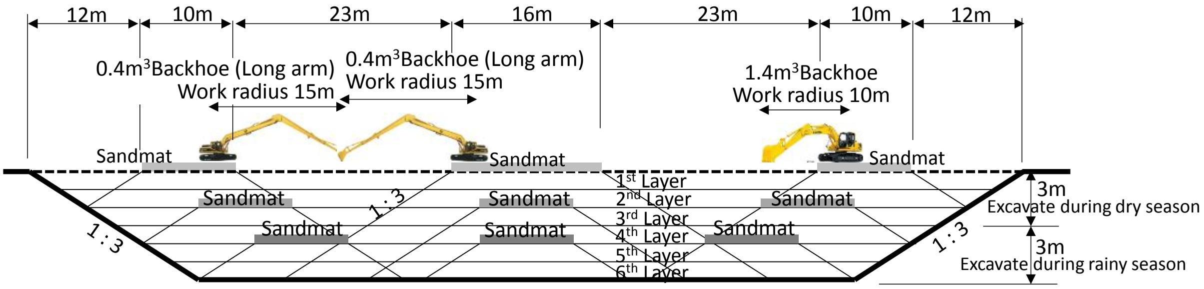
8) Prefabricated Vertical Drain (PVD)

Sand mat will be laid in the Prefabricated Vertical Drain (PVD) installation area, the purchased sand will be transported by the10t-class dump trucks. Subsequently, scattered sand from dump truck will be laid by a 15t-class bulldozer. PVD will be installed by a 0.8m^3-class base machine attached with casing.

(5) Excavation

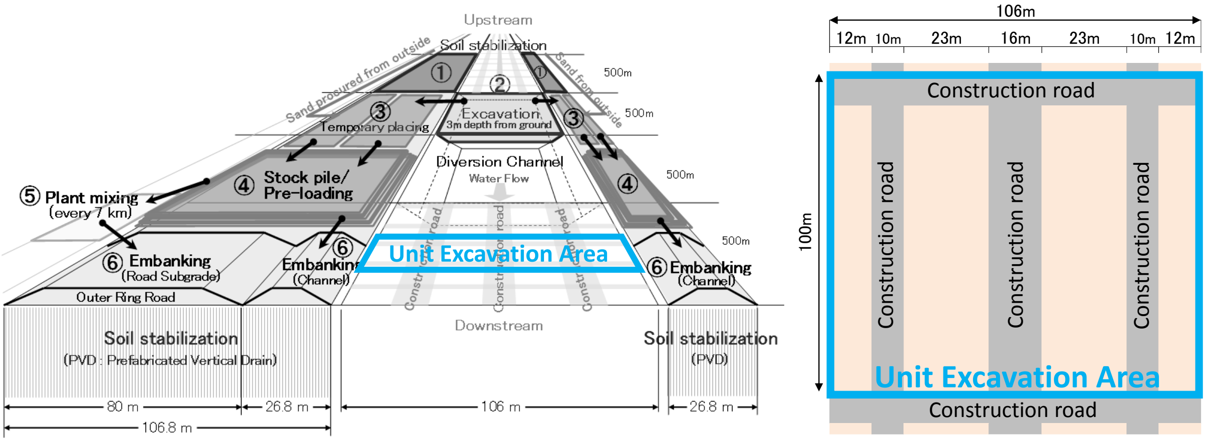
The method of excavating the Diversion Channel is basically as follows. This method was examined with reference to the construction method of the Suvarnabhumi Airport Drainage Channel in Thailand. The excavation method is considered to be different in the north part, central part, and south part, depending on the soil condition of the excavation area. Therefore, the optimal method according to the soil condition of each part is adopted based on the methodology shown below.

- Excavation of the Diversion Channel is carried out by considering the stability of the excavation surface and installation of a heavy machine inside the channel. When the excavation is carried out with heavy machines placed outside the excavation area, there is a danger of causing sliding failure in the already excavated area. Therefore, avoid placing the heavy machines outside the waterway, should be avoided.
- In order to place the heavy machines for excavation, side road is constructed in the area to be excavated. The road is constructed with 50 cm thick sand layer.
- Excavation of 6 m deep is necessary for the construction of the Diversion Channel. The excavation shall be divided into 6 layers with a thickness of 1 m each. After excavation of one layer, there shall be a separation by a period of several days before the excavation of the next layer. This will increase and maintain the stability of the excavation surface.
- The gradient of the excavated slope shall be 1:3.
- Excavation from ground level to 3 m in depth shall be done during the dry season (November to April), and the next excavation from 3 m to 6 m in depth shall follow during the rainy season (May to October).
- 1.4 m^3 class backhoe, with work range of 10 m, will be used for excavation in area that is less than 10m away from the edge of construction road. As for area of 10 ~ 15m away, 0.4m^3-class backhoe with a 15m-long arm will be used.



Source : JICA Study Team

Figure 3.1.12 Cross section image of the Diversion Channel excavation



Source : JICA Study Team

Figure 3.1.13 Explanation of Unit Excavation Area

(6) Temporary Placing

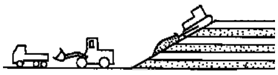
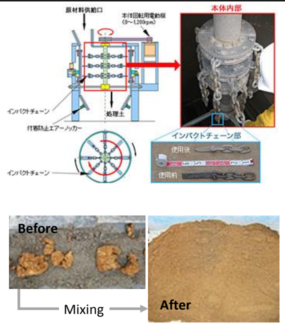
Soil which is not deeper than 3 m from the ground level and excavated during the dry season can be utilized as an embankment material, thus it shall be temporarily placed in designated area.

(7) Preparing Stock Pile / Pre-Loading

Regarding the method for mixing clay and sand, the following four methods shown in the table below are proposed. Level-1 and Level-2 are for the use of soil mixtures as a material for the construction of the Diversion Channel embankment, while Level-3 and Level-4 are used for the Outer Ring Road embankment.

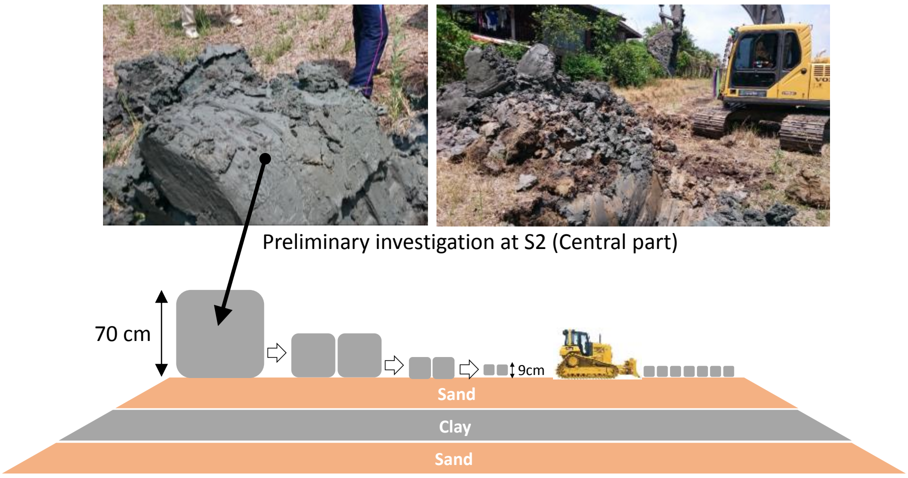
Table 3.1.3 Mixing methods of clay and sand

Simple mixing ⟷ Plant mixing

	Level-1	Level-2	Level-3	Level-4
	Stock-Pile	Mixing by Stabilizer	Plant Mixing	Twister Mixing (Rotary crushing and mixing)
Mixing Method	Push down stock-pile by bulldozer and drop pushed down soil about three times by wheel loader  ＜Stock-Pile Preparing Method＞ 1) Excavate clay by clamshell or Backhoe 2) Dry up excavated clay under sun shine during temporary placing and split mass clay into small pieces 3) Prepare stock-pile stacking clay and sand alternately	Mix at embanking work site by Stabilizer 	Set up stationary type plant. Clay and sand that are put into this plant will be stirred and mixed. 	
Application	This method is adopted aiming to shorten construction period and reduce construction cost.	This method is adopted as an additional process to Level-1 method if mixing using Level-1 method is insufficient.	This method is adopted to mix more carefully than Level-2 method. If clay and sand mixing is difficult, Level-4 method is adopted.	This method is adopted to mix three or more kinds of materials for example clay, sand and lime. Plant mixing except for this method can mix only two kinds of materials.

Source : JICA Study Team

For all the mixing methods shown in Table 3.1.3, it is necessary to consider an appropriate method according to the situation at the construction site. The results of the study are shown below. Regarding the Level-1, the stockpile where clay and sand are stacked alternately is created in the planned embankment area on the left and right banks of the Diversion Channel. The area of the bottom of the stock pile shall be approximately 5,000 m^2 (about 100 meters in width and about 500 meters in length in the upstream and downstream direction) on the right bank, and approximately 3,000 m^2 on the left bank (about 30 meters in width and about 500 meters in length in upstream and downstream direction). Stockpile shall be built during the dry season in approximately 150 days. The mass volume of clay immediately after excavation is assumed to be approximately 70 cm. The clay shall be placed on a layer of sand and sliced to a required size by backhoe or manpower work and then dry it on the sun at the same time.



Source : JICA Study Team

Figure 3.1.14 Stock Pile stacking clay and sand alternately

(8) Plant mixing

Mixed soil (excavated clay soil mixed with purchased sand) can be utilized as embankment material. For the subgrade, California Bearing Ratio (CBR) of the mixed soil shall be larger than 4%. Therefore, soil from stockpile needs further mixing in plant. As for the base, uniaxial compressive strength larger than 400kN/m^2 (kPa) is required. This value is the same with the material for the dike embankment and soil from stockpile can be directly used to embank the dike. However, considering the importance of the Road where traffic load constantly applies, plant mixing may be necessary for the base.

(9) Embanking

The dike will be embanked and compacted by using soil from stockpile with inter-stratification of sand and clay. As for the road, mixed soil from stockpile will be further mixed in mixing plant and then embanked and compacted.

3.1.10 Process plan

Each section is 2km long which is composed of four 500m-long units. Construction schedule for each section is shown in following figure. For one section, construction, from removal of existing facilities to embankment, will be completed in 5 years. In order to finish the whole combined project in 5 years, construction shown in following table must be on operation simultaneously in all 55 sections.

Table 3.1.4 Construction schedule of the Section (Northern part)

Work items			Work days		1st year		2nd year		3rd year		4th year		5th year	
					Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
					75days	150days	75days	150days	75days	150days	75days	150days	75days	150days
(1) Removal Existing Facilities			75		Unit 1～4									
(2) Reclamation / Laying Construction Road			0											
(3) Changing Route of Existing Channel			75											
(4) Soil Stabilization			0		Unit 1,2	Unit 3		Unit 4						
(5)	(a) Transportation（Sand mat)		65			Unit 2		Unit-3		Unit 4		Unit 1'		
	(b) Excavation (depth 0-3m) (Dry season)	Laying Con.Road	34	138		Unit 2		Unit-3		Unit 4		Unit 1'		
		Excavation	104			Unit 2		Unit-3		Unit 4		Unit 1'		
		Soil disposal	174			Unit 2		Unit 3		Unit 4		Unit 1'		
	(c) Excavation (depth 3-6m) (Rainy season)	Laying Con.Road	15	71			Unit 2		Unit-3		Unit 4		Unit 1'	
		Excavation	56				Unit 2		Unit-3		Unit 4		Unit 1'	
		Soil disposal	181											
(6) Temporary Placing			106			Unit 2		Unit 3		Unit 4		Unit 4 *1		
(7)	(a) Preparing Stock Pile / Pre-Loading (Channel)		150			Unit 1		Unit 2		Unit 3		Unit 4		
	(b) Preparing Stock Pile / Pre-Loading (Road)					Unit 1		Unit 2		Unit 3		Unit 4		
(8) Plant Mixing														
(9)	(a) Embanking (Chnnel)		143					Unit 1		Unit 2		Unit 3		Unit 4
	(b) Embanking (Road)		133					Unit 1		Unit-2		Unit 3		Unit 4

"Unit 1" locates at the most downstream position in the "Section".
"Unit 2" locates at the second position from downstream in the "Section".
"Unit 3" locates at the third position from downstream in the "Section".
"Unit 4" locates at the most upstream position in the "Section"
"Unit 1' " is adjacent to the upstream side of "Unit 1".
*1: Temporary placing at the bottom of the channel in the downstream adjacent Unit. Excavation shall be already completed in this Unit.

Source : JICA Study Team

Table 3.1.5 Construction schedule of the Section (Central part)

Work items			Work days		1st year		2nd year		3rd year		4th year		5th year	
					Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
					75days	150days	75days	150days	75days	150days	75days	150days	75days	150days
(1) Removal Existing Facilities			75		Unit 1～4									
(2) Reclamation / Laying Construction Road			0											
(3) Changing Route of Existing Channel			75											
(4)	(a) PVD (Rany season)	Sandmat	25	75	Unit 1,2	Unit 3		Unit 4						
		PVD Installation	50		Unit 1,2	Unit 3		Unit 4						
	(b) SCC (Rainy season)	SCC Installation	75		Unit 1,2	Unit 3		Unit 4						
	(a) PVD (Dry season)	Sandmat	23	147	Unit 1,2	Unit 3		Unit 4						
		PVD Installation	125		Unit 1,2	Unit 3		Unit 4						
	(b) SCC (Dry season)	SCC Installation	150		Unit 1,2	Unit 3		Unit 4						
(5)	(a) Transportation（Sand mat)		65			Unit 2		Unit-3		Unit 4		Unit 1'		
	(b) Excavation (depth 0-3m) (Dry season)	Laying Con.Road	34	138		Unit 2		Unit-3		Unit 4		Unit 1'		
		Excavation	104			Unit 2		Unit-3		Unit 4		Unit 1'		
		Soil disposal	174			Unit 2		Unit 3		Unit 4		Unit 1'		
	(c) Excavation (depth 3-6m) (Rainy season)	Laying Con.Road	15	71			Unit 2		Unit-3		Unit 4		Unit 1'	
		Excavation	56				Unit 2		Unit-3		Unit 4		Unit 1'	
		Soil disposal	181											
(6) Temporary Placing			106			Unit 2		Unit 3		Unit 4		Unit 4 *1		
(7)	(a) Preparing Stock Pile / Pre-Loading (Channel)		150			Unit 1		Unit 2		Unit 3		Unit 4		
	(b) Preparing Stock Pile / Pre-Loading (Road)					Unit 1		Unit 2		Unit 3		Unit 4		
(8) Plant Mixing														
(9)	(a) Embanking (Chnnel)		125					Unit 1		Unit 2		Unit 3		Unit 4
	(b) Embanking (Road)		142					Unit 1		Unit-2		Unit 3		Unit 4

"Unit 1" locates at the most downstream position in the "Section".
"Unit 2" locates at the second position from downstream in the "Section".
"Unit 3" locates at the third position from downstream in the "Section".
"Unit 4" locates at the most upstream position in the "Section"
"Unit 1' " is adjacent to the upstream side of "Unit 1".
*1: Temporary placing at the bottom of the channel in the downstream adjacent Unit. Excavation shall be already completed in this Unit.

Source : JICA Study Team

Table 3.1.6 Construction schedule of the Section (Southern part)

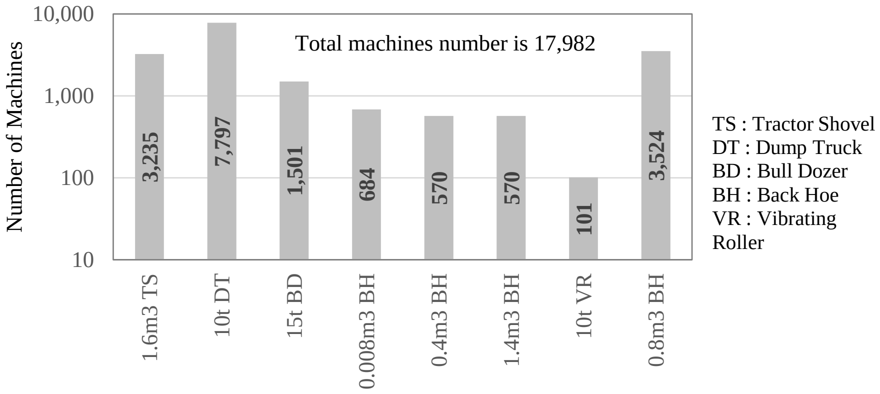
Work items			Work days		1st year		2nd year		3rd year		4th year		5th year	
					Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
					75days	150days	75days	150days	75days	150days	75days	150days	75days	150days
(1) Removal Existing Facilities			75		Unit 1～4									
(2) Reclamation / Laying Construction Road			75											
(3) Changing Route of Existing Channel			75											
(4)	(a) PVD (Rany season)	Sandmat	25	75	Unit 1,2	Unit 3		Unit 4						
		PVD Installation	50		Unit 1,2	Unit 3		Unit 4						
	(b) SCC (Rainy season)	SCC Installation	75		Unit 1,2	Unit 3		Unit 4						
	(a) PVD (Dry season)	Sandmat	29	148	Unit 1,2	Unit 3		Unit 4						
		PVD Installation	119		Unit 1,2	Unit 3		Unit 4						
	(b) SCC (Dry season)	SCC Installation	148		Unit 1,2	Unit 3		Unit 4						
(5)	(a) Transportation（Sand mat)		65			Unit 2		Unit-3		Unit 4		Unit 1'		
	(b) Excavation (depth 0-3m) (Dry season)	Laying Con.Road	34	138		Unit 2		Unit-3		Unit 4		Unit 1'		
		Excavation	104			Unit 2		Unit-3		Unit 4		Unit 1'		
		Soil disposal	174			Unit 2		Unit 3		Unit 4		Unit 1'		
	(c) Excavation (depth 3-6m) (Rainy season)	Laying Con.Road	15	71			Unit 2		Unit-3		Unit 4		Unit 1'	
		Excavation	56				Unit 2		Unit-3		Unit 4		Unit 1'	
		Soil disposal	181											
(6) Temporary Placing			106			Unit 2		Unit 3		Unit 4		Unit 4 *1		
(7)	(a) Preparing Stock Pile / Pre-Loading (Channel)		150			Unit 1		Unit 2		Unit 3		Unit 4		
	(b) Preparing Stock Pile / Pre-Loading (Road)					Unit 1		Unit 2		Unit 3		Unit 4		
(8) Plant Mixing														
(9)	(a) Embanking (Chnnel)		125					Unit 1		Unit 2		Unit 3		Unit 4
	(b) Embanking (Road)		0					Unit 1		Unit-2		Unit 3		Unit 4

"Unit 1" locates at the most downstream position in the "Section".
"Unit 2" locates at the second position from downstream in the "Section".
"Unit 3" locates at the third position from downstream in the "Section".
"Unit 4" locates at the most upstream position in the "Section"
"Unit 1' " is adjacent to the upstream side of "Unit 1".
*1: Temporary placing at the bottom of the channel in the downstream adjacent Unit. Excavation shall be already completed in this Unit.

Source : JICA Study Team

3.1.11 Procurement plan

The required machines number in one section during every half year (dry season or rainy season) were estimated, for each part (North part, Central part or South part). The maximum required number of each machine during 5-year construction period was as well estimated. Number of each machine that should be procured can be estimated by multiplying above mentioned maximum machine number in each part by the number of sections in each part. Estimation result is shown in Figure 3.1.14. Maximum number of machines that should be procured is roughly 18,000 at the peak time.



Source : JICA Study Team

Figure 3.1.15 Required machines number (Peak period)

3.2 Operation and Maintenance Plan

3.2.1 Operation of intake gate and tidal gate

The Diversion Channel is required to discharge maximum 500 m^3/s by operating two gates at upstream and downstream. RID needs to define the operation rules of two gates by considering the water level at the Chao Phraya River and the Pasak River, inundation conditions and water usage of river basin, and the additional functions of diversion channel.

Based on water resources management practice in the Chao Phraya River basin, there are two seasons for water allocation, wet and dry season. For water resources management in Thailand, wet season covers period from May 1 – October 31 and dry season covers period from November 1 – April 30. Water resources management plan is prepared by Water Allocation Division, Water Management Sector, Office of Water Management and Hydrology in advance in order to guide the responsible offices under RID. There are two plans for Water resources management in wet season. The first plan is for prevention and mitigation, focusing on flood management and reservoir operation. The second plan is for water allocation for cultivation in wet season, focusing on available water in reservoirs and irrigated area plan. While, water resources management in dry season focuses on managing available water to sectors with demand and plan for possible irrigation area. The objectives for the water resources management in wet and dry season are different, therefore, the operation regulators in upstream and downstream of the Diversion Channel shall be related to the seasonal water resources management plan in the Chao Phraya River basin.

(1) Wet season (May – October)

Designed discharge of Diversion Channel is 500 m^3/s. Function of the Diversion Channel is as a new river. Since the water level in the Diversion Channel is designed to be higher than the ground level, thus, hydraulic gradient from upstream to downstream has a potential to discharge water to the sea without pumping station even during the tidal period.

The intake gate is operated in accordance with the discharge the Chao Phraya River. There are several methods for operating the gate, such as, the method to discharge the fixed rate of discharge the Chao Phraya River, the method to increase the discharge gradually by keeping the same discharge the Chao Phraya River, and the method to increase the discharge by steps according to the discharge the Chao Phraya River.

The tidal gate is operated by considering the opening of the intake gate, the water level at the upstream of tidal gate and the tidal level. When the tidal level is higher at the end of the flood season, the tidal gate is closed, and the flow from the Diversion Channel can be discharged by the pumping stations at the Chay Talay Channel.

(2) Dry season (November – April)

Since the water level of the Diversion Channel during the dry season is as low as that of the ground level, the tidal gate is basically closed from the point to prevent the salinity intrusion. On the other hand, the intake gate can be opened temporary for the maintenance purpose, and the flow from the Diversion Channel can be discharged by the pumping stations at the Chay Talay Channel, if necessary. Table 3.2.1 shows the summary of operation method of the two gates.

Table 3.2.1 Operation of two gates

Season	Wet Season	Dry Season
Intake Gate	The gate is operated according to the flood situation.	The gate can be opened temporary for the maintenance purpose.
Tidal Gate	The gate is operated by considering the opening of the intake gate, water level at the upstream of tidal gate and tidal level.	The gate is basically closed. The gates and the pumping stations of the Chay Talay Channel are operated to drain the water from the Diversion Channel, if necessary.

Source : JICA Study Team

3.2.2 Maintenance work of facilities

There are the intake gate, the tidal gate, the channel and the siphons as the major facilities to be maintained of the Diversion Channel. Table 3.2.2 shows the major maintenance work of the facility.

Table 3.2.2 Maintenance work of facilities

Facility	Maintenance Work
Gate	● RID has guideline on operation and maintenance of gate and hoist equipment for operating officers. ● After gates and equipment are installed, the equipment will be tested and operation manual for gates operation will be prepared. ● In the Chao Phraya River, many water hyacinth flow in the river when gates open. Preventing net should be installed at the upstream of the gate. Project officers at the gate will collect water hyacinth at preventing net by boat.
Channel	● Sediment in the Diversion Channel should be checked and dredged in dry season. ● Since the Diversion Channel is earth channel, many weeds will grow on the channel slope and berm. It should be removed in dry season in order to improve channel capacity. ● When the weeds grow, its root will destroy channel slope and berm. Water flow in wet season also erodes channel surface. After Diversion Channel is inspected, weak points will be found and improved. ● Sodding is on Diversion Channel slope to prevent erosion in the channel. In some areas, grass will be lost from weed and other factors. Sodding should be filled with grass in lost areas during wet season.
Siphon	● Dredging sedimentation at the entrance of siphon and cut trees on channel bank to prevent flow obstruction in siphon. ● If siphon is damaged, it should be fixed immediately. ● Trash rack should be installed for preventing tree branches and garbage flow in the siphon. ● Check siphon structure in dry season with low water level, if crack is found on siphon wall, it should be fixed immediately.

Source : JICA Study Team

3.2.3 Monitoring system

RID has established Smart Water Operation Center (SWOC) for water resources management in basin level which links data and information with relevant agencies, such as Meteorological Department (MD), Electricity Authority of Thailand (EGAT), Hydrographic Department (HD), etc. Water level data monitored at gauging stations and flow data through regulator will be sent directly to Smart Water Operation Center. Diversion Channel will be a part of water resources management function in the Chao Phraya River basin. Gates adjustment for opening and closing at upstream and downstream of Diversion Channel are related to water situation in the basin. The integration with existing water management system is required for the real time operation especially during flood situation which fulfills the project objective to accelerate release of flood from upstream area.

3.2.4 Role allocation of DOH and RID for maintenance of facility

(1) Role allocation of operation and maintenance

This project is composed of two projects, the Diversion Channel and the Outer Ring Road. After the completion of the project, DOH and RID have to cooperate for the maintenance work of the two infrastructures, including supplementary facilities. There are three options on the maintenance system and budget allocation for the maintenance of these facilities.

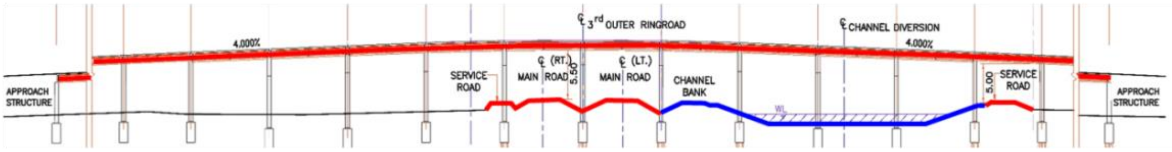
< Option 1: Role allocation by “Function” of facilities >
The roles for the maintenance of facilities are allocated by “Function” to be performed by the facilities, regardless the agencies which own the land. RID maintains the channel, dikes, gates and siphons etc., while the roads and bridges are maintained by DOH.

< Option 2: Role allocation by “Land” of facilities >
In this case, RID maintains the roads and bridges, if those facilities are constructed on the land of RID. For example, the service roads on the dikes of diversion channel and the part of the bridges flying over the Diversion Channel are maintained by RID.

(2) Role allocation of cost for operation and maintenance

In this case, specialized agencies maintain their responsible facilities, but the cost is owned by the land owing agencies. For example, the service roads on the dikes of diversion channel are maintained by DOH because of their function, but their cost is burdened by RID.

1. Role allocation by “Function”



2. Role allocation by “Land”

Red: Maintained by DOH, Blue: Maintained by RID

Source : JICA Study Team

Figure 3.2.1 Role allocation of DOH and RID on maintenance

Table 3.2.3 shows the advantages and disadvantages of the above options.

Table 3.2.3 Maintenance Work of Facilities

Option	Advantages	Disadvantages
1) Function	● Specialized agency manages their responsible facilities. ● Budget request is simple.	● Cost of DOH for management of bridges etc. is increased due to the crossing at the Diversion Channel. ● Management of service road on the channel dike is complicated.
2) Land	● Cost allocation for management is equal. ● Role allocation is simple.	● Some facilities are managed by non-specialized agency. ● Budget request is complicated for non-responsible facilities. The maintenance of the road inside the Diversion Channel site will be done by the organization that constructs the channel. Therefore, there is concern that the division of responsibility may become ambiguous.
3) Cost Allocation	● Specialized agency manages their responsible facilities. ● Cost allocation for management is fair (Increment of maintenance cost by participation of Diversion Channel can be burdened by the channel constructing organization as a trigger).	● Budget request is complicated for non-responsible facilities.

Source : JICA Study Team

3.3 Environmental and Social Consideration

The following is the consideration of possible impacts of the construction of the Outer Ring Road Diversion Channel on natural and social environment.

3.3.1 Process of Environmental Impact Assessment (EIA) for construction of the Diversion Channel

(1) Necessity of EIA for the project

In principle, necessity of EIA for the project is determined in accordance with the current law in Thailand "National Environment Quality Act (NEQA, 1992)" and specific operational rule "Environmental Impact Assessment in Thailand, 2015, ONEP". According to "Types and sizes of projects or activities requiring preparation of Environmental Impact Assessment reports", this project will possibly fall under the following three project type categories. Especially at the periphery of outlet of the Diversion Channel, possible impact on "Mangrove forests designated as National Forest Reserve" will have to be considered.

- 20. Highway or road which defined by the Highway Act. passing through the following areas (especially, "20.4 Mangrove forests designated as National Forest Reserve" will have to be considered）
- 34. Trans Basin Diversion
- 35. Sluicegate in the Major River

(2) Review and approval process of EIA report

According to "Environmental Impact Assessment in Thailand, 2015, ONEP", this project corresponds to the joint project implemented by government agency, state enterprise and private company.

Hence, EIA report which will be prepared by EIA consultants licensed by the Office of Natural Resources and Environmental Policy and Planning (ONEP) at the stage of conducting feasibility study (F/S), will have to be subjected to a review by the National Environment Board (NEB) and approval by the Cabinet.

EIA review process for project or activity of government agency, state enterprise, or to be jointly undertaken with private enterprises which requires the approval of the Cabinet is detailed below.

In accordance with the NEQA (1992), the project proponent shall have the duty to prepare the EIA report at the stage of conducting feasibility study and submit the EIA report to NEB for its review and comments, after which the EIA report will then be submitted to the Cabinet for its consideration. However, in practice, the EIA report will be submitted to ONEP, and ONEP will examine the EIA report, make preliminary comments and then refer ONEP's preliminary comments to the ERC for consideration before submitting comments of the ERC to NEB. If the EIA report is approved by the Cabinet, the official legally empowered to grant permission shall accordingly order that the permission be granted to the agency responsible for the project.

According to "Environmental Impact Assessment in Thailand, 2015, ONEP", description of rules on land acquisition and involuntary relocation, which prescribe land acquisition process only, is relatively scarce compared to common international standards such as IFC Performance Standards.

However, public participation/meeting will have to take place at least two times (1) at the stage of scoping the EIA study and (2) at the stage of drafting the EIA report.

Currently, the FS and public meetings in EIA of the Outer Ring Road project had been completed, being awaiting for the approval.

Therefore, shortening of the duration of FS and EIA of the Diversion Channel project will have to be sought by employing several EIA consultant firms and holding public meeting at several provinces around the same time.

Source : Environmental Impact Assessment in Thailand, 2013, ONEP

Figure 3.3.1 Approval process for projects or activities required the approval of the cabinet

3.3.2 Possible environmental impact and mitigation measures in the Diversion Channel Construction

The following is the consideration of possible natural and social environmental impact and mitigation measures in the Diversion Channel construction.

Table 3.3.1 Possible environmental impact and mitigation measures

Possible impact	Phase	Possible mitigation measures
Air pollution	Construction	• Prevention of dust and sand littering to the atmosphere →Water sprinkling on the bare ground, washing of the construction vehicles →Installation of dust prevention net
	Operation	• Prevention of sand littering to the atmosphere →Grass and tree planting on the bare ground
Water pollution	Construction	• Prevention of sediment discharge to the irrigation canals →Coating sheet on the soil stockpile, installation of sedimentation pond • Maintenance of function of the irrigation/drainage canal →Utilization of lifting and drainage pumps • Proper disposal of wastewater and human waste from the construction site →Utilization of water-purifier and oil removal tanks
	Operation	• Maintenance of function of the irrigation/drainage canal →Maintenance of siphons and sluicegates
Waste	Construction	• Proper disposal of waste from the construction site
	Operation	• Maintenance of the public health →installation of sanitary facilities such as toilet and waste-collection points to the open spaces
Noise and vibration	Construction	• Compliance with labor time standard (including material handing time) • Compliance with maximum load and velocity of the construction vehicles (Maximum load including carrying weight should be less than 25 tons) • Installation of sound abatement shield • Utilization of low-noise construction machinery (excavation, surface compaction, piling, etc.) • Utilization of precast construction components (bridge superstructure, sheet pile, pile, etc.)
Biota and ecosystem	Construction/ Operation	• Conservation and maintenance of mangrove and wetland along the coastal area →Afforestation and restoration of mangrove at the periphery of outlet of the Diversion Channel
Involuntary resettlement	Construction/ Operation	• Minimization of land acquisition area and involuntary relocation number →Optimization of the Diversion Channel alignment • Promotion of re-establishment of the relocated resident →Application of appropriate compensation for property (land, house, building, tree, etc.) →Reconstruction of residential area of new address
Local economy such as employment and livelihood	Construction	• Employment of the local residents for the construction works
	Operation	• Utilization of open water and space →Maintenance of river terrace (community park) and green belt • Smoother flow of traffic in the local community area
Cultural heritage	Construction/ Operation	• Conservation of historical and cultural heritage →Optimization of the Diversion Channel alignment
Landscape and scenery	Construction/ Operation	• Improvement landscape and scenery →Landscape architecture of the bridge structures →Maintenance of grass and tree planting at the community park and the green belt
Accidents	Construction	• Prevention of traffic accident →Installation of safety facility (sign, fence, security guard, night lighting, etc.) • Prevention of falling object from the construction site →Utilization of sheet covering truck carrier, anti-drop net, etc.

Source : JICA Study Team

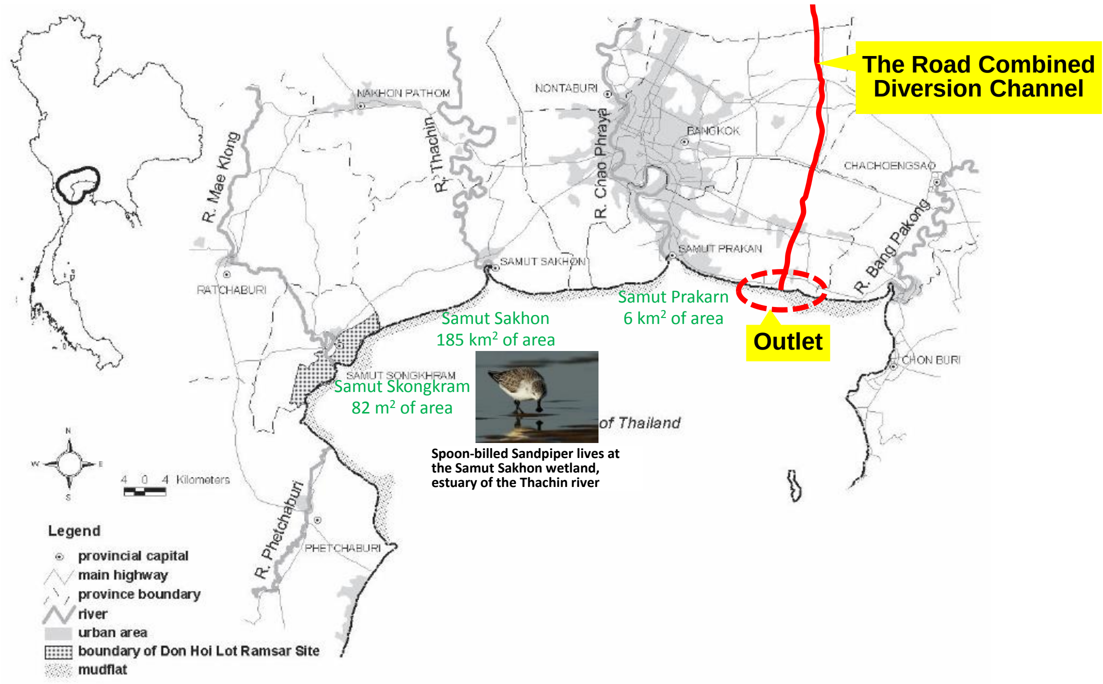
3.3.3 Conservation measures of mangroves along the coastal area

(1) Current status of mangrove wetland in the Gulf of Thailand

“Mangrove” is a general term for halophilous trees (and those ecosystem) which grows along coastal and estuarine area in tropical and subtropical regions. Mangrove wetland in the Gulf of Thailand is regarded as a valuable environment with one of the foremost rich ecosystem in Asia. However, mangrove wetland in the Gulf of Thailand is exposed to development pressures from aquaculture industry (prawn, crab, shellfish, etc.). Besides, water contamination (agrichemical/fertilizer from rural part and municipal/industrial effluent from urban area) make an impact on mangrove wetland. Recently, productivity of aquaculture industry is declining due to environmental deterioration after destruction of mangrove wetland. Thus, benefit of sustainable aquaculture industry from conservation and restoration of coastal environment become recognized as a consequence. Also, mangrove within Inner Gulf of Thailand is designated as Thai national forest reserve (2000 August, cabinet decision) and wetland within Inner Gulf of Thailand is nominated for the Ramsar Convention registration.

(2) Mangrove wetland within Inner Gulf of Thailand

Within Inner Gulf of Thailand, about 273 km^2 total area of mangrove wetland (Samut Songkram 82 km^2, Samut Sakhon 185 km^2, Samut Prakarn 6 km^2) is found along about 116 km coast line extension. Some experts suggests that major occurrence factor of physical eternal force toward mangrove wetland is coastal current caused by tidal force, while the influence of wind stress and density difference is negligible. Also, average salinity concentration is 2.9% (fluctuation range 0.38%) and average seawater temperature is 29.2°C (fluctuation range 3.3°C) in surrounding ocean area.



Spoon-billed Sandpiper lives at the Samut Sakhon wetland, estuary of the Thachin river

Source : Shorebirds in the Inner Gulf of Thailand, Philip Round, 1998

Figure 3.3.2 Areas of mangrove wetland within Inner Gulf of Thailand

Aquaculture pond

Mangrove wetland

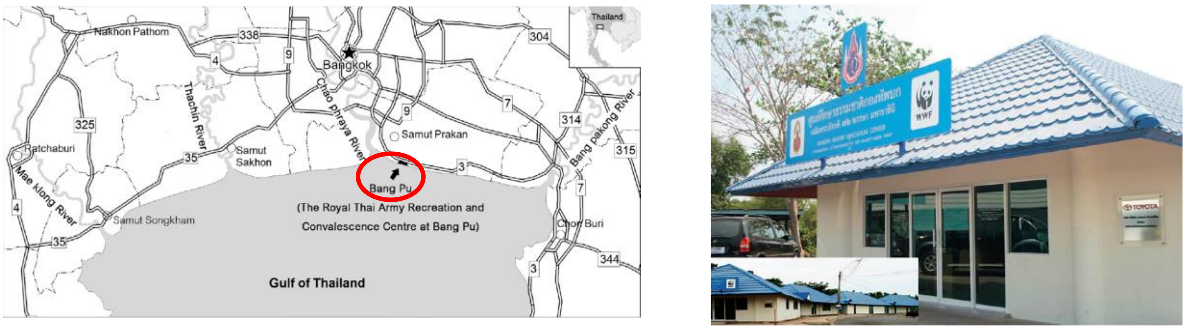
Wat Si Chanthraram

Source：JICA Study Team

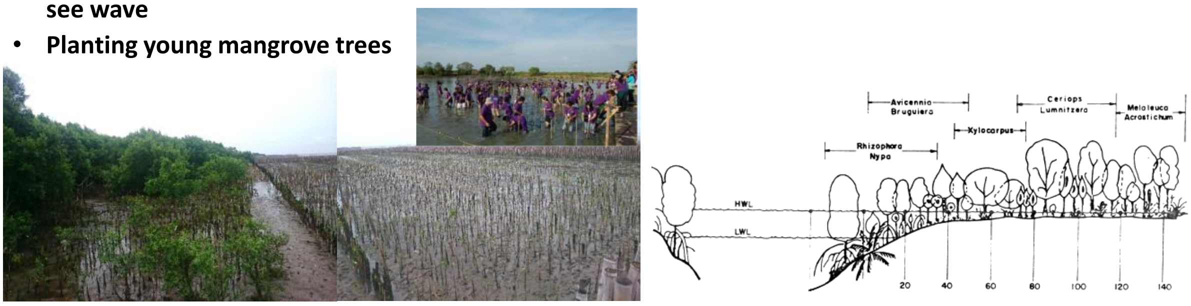
Figure 3.3.3 Current land use around the outlet of the Diversion Channel

(3) Conservation measures of mangrove

As a good practice of conservation measures of mangrove in Thailand, environment education is provided through conservation of mangrove wetland and afforestation of mangrove trees in the Royal Thai Army Recreation and Convalescence Center at Bang Pu on the east side of the Chao Phraya River estuary. At the outlet of the Diversion Channel, land acquisition and mangrove trees cutting down will be unavoidable. Hence, in compensation for those impact, an equivalent area of mangrove afforestation and restoration should be considered. And, accumulated experience and knowledge at the Bang Pu Center could serve as a useful reference.

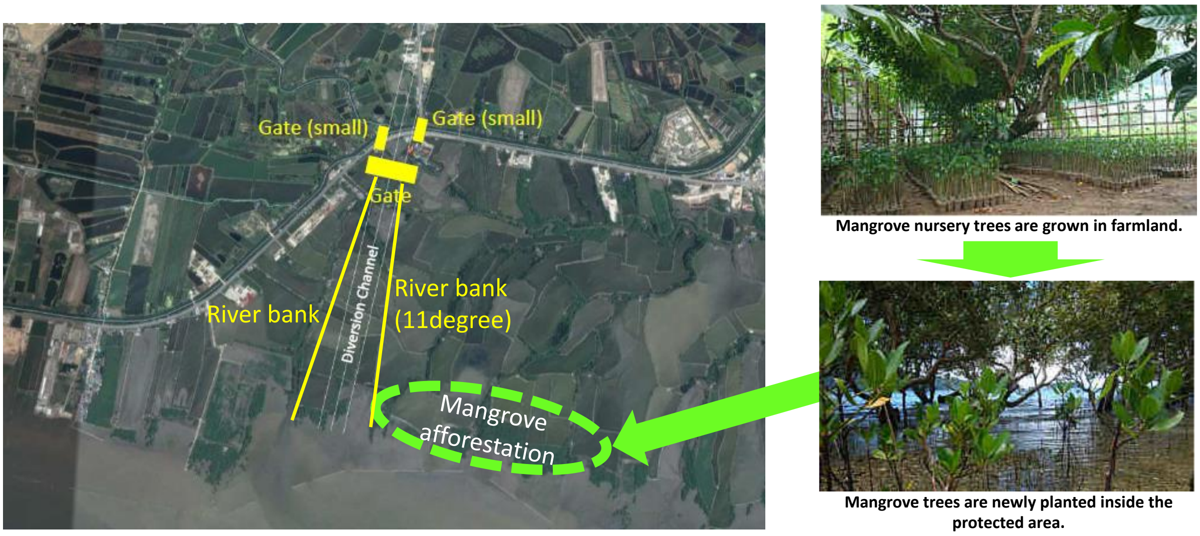


- **Rehabilitation of mangrove forest along the shoreline by making bamboo or rock-pile to protect from see wave**
- **Planting young mangrove trees**



Source：Bang Pu: Thailand's First Urban Nature Education Centre、2012, John W. K. Parr

Figure 3.3.4 Afforestation and restoration of mangrove at the Bang Pu Center



Mangrove nursery trees are grown in farmland.

Mangrove trees are newly planted inside the protected area.

Source : JICA Study Team

Figure 3.3.5 Image of compensatory approach of mangrove conservation

(4) Way forward to implement EIA on conservation of mangrove

Compensatory approach an equivalent area of mangrove afforestation and restoration should be considered for unavoidable cutting down of existing mangrove trees around the outlet of the Diversion Channel.

When the EIA concerned with the Diversion Channel is implemented, consultation will be necessary with not only ONEP, but also and with the Department of Marine and Coastal Resources (DMCR), who is in charge of mangrove conservation. MNRE is very cooperative because the Diversion Channel project is the important national project.

On the other hand, when the FS and EIA concerned with the Eastern Diversion Channel project is implemented, impact assessment of mangroves with prolonged freshwater exposure during times of flooding is conducted. So, the same sort of assessment will be required for the Diversion Channel project as well.

3.4 Project Cost Estimation

3.4.1 Estimation of the Project Cost of the Diversion Channel

Table 3.4.1 shows estimated project cost of the Outer Ring Road Diversion Channel. Construction cost has been estimated in this study as a total of channel construction cost and facility cost. Project cost estimation was done refer to the Thailand’s method. Engineering cost / Construction cost and Project management cost / Processing were calculated multiplying Construction cost by several rate. Value added tax was not included in the project cost referring to Thailand’s method. Land cost / Compensation was estimated in this study according to the unit price and estimation method in Thailand. Based on the above way, project cost has been calculated using formulas shown in the remark in the following table.

Table 3.4.1 Project cost of the Diversion Channel

Items	Amount （Million THB）	Remark
Construction Cost	71,949	a)
Engineering Cost / Construction Control	5,756	b)=a)×0.08
Project Management Cost / Processing	2,158	c)=a)×0.03
Value Added Tax	0	d)
Land Cost / Compensation	52,450	e)
Project Cost	132,314	f)=a)+b)+c)+e)

Source: JICA Study Team

3.4.2 Estimation of the Outer Ring Road Construction Cost

The result of estimation of the road construction cost is shown in Table 3.4.2. Regarding the comparison table between the Feasible Study by DOH and this estimation, see “Supporting Report 11: Project Cost Estimation”. The project cost of the Outer Ring Road was estimated in the Feasibility Study conducted by DOH from 2006 to 2008. However, when combined development of the Diversion Channel and the Outer Ring Road is assumed and the estimated cost in the Feasibility Study is reviewed since the road structure is changed as shown in Section 2.4.3 The Outer Ring Road. Moreover, the number of construction inputs and the unit costs in the Feasibility Study are also reviewed to reflect those changes caused by the change of road structure and inflation between 2008 to 2017. The method to review the unit price of construction inputs is written below:

< When the Cost Breakdown exist >

When the cost breakdown in the Feasibility Study by DOH exists, i.e. ground making, pavement, those unit costs are revised by replacing unit costs of construction materials, labor and operation adopted in the Feasibility Study to the latest ones.

< When the Cost Breakdown does not exist >

When the cost breakdown in the Feasibility Study by DOH does not exist, i.e. bridge, unit costs are revised by using “adjustment factors”, which is calculated from multiplying the cost increase of construction materials, labor and operation by the general ratio of each cost to the construction cost of each facility.

The result of the estimation is shown in Table 3.4.2.

Table 3.4.2 Road construction cost

	① This Study	② After F/S Review	③ F/S 2011
Direct Construction Cost	48,629	45,162	26,073
Indirect Construction Cost	6,322	5,871	3,500
Construction Cost	54,951	51,033	29,573

Indirect construction cost is estimated multiplying direct construction cost by Factor-F(0.13 Unit : Mil. THB

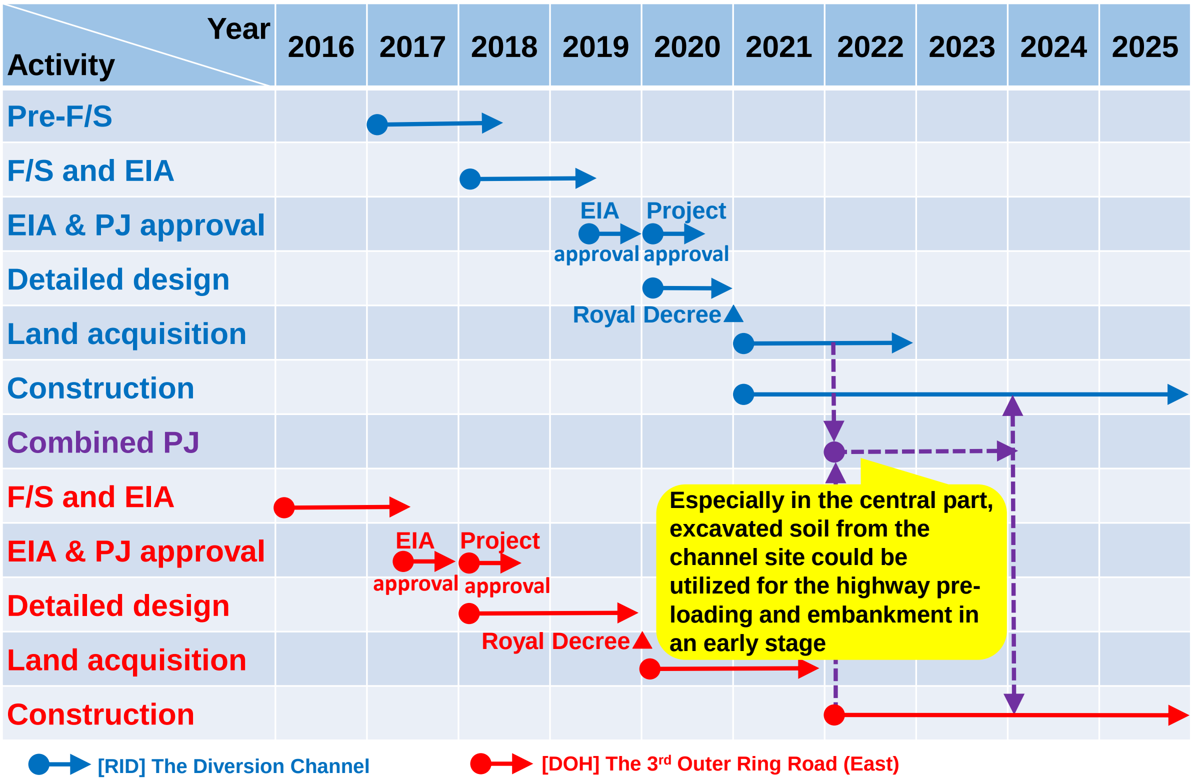
Source: JICA Study Team

Construction cost in the above table includes increased cost of interchange modification and increased cost of overpass crossing with the channel. As of current situation, these costs are estimated as an increased cost that is allocated to DOH. When the feasibility of the Road and Channel combined project become clear, the discussion between RID and DOH regarding cost allocation and more reducing of road construction cost will be promoted. Measures to reduce construction cost allocated to DOH will be described after the above discussion will be concluded.

3.5 Project Implementation Schedule

DOH has been implementing F/S and EIA for the Outer Ring Road project ahead of this integrated project. Therefore the implementation schedule of the Diversion Channel was planned with priority so it will not affect the road implementation plan. The priority in the construction schedule should be considered pre-loading. For the construction of the road embankment on soft ground, pre-loading is needed. Therefore, excavation will start immediately from the area where the land acquisition has done, and the excavated soil will be used as pre-load material. The construction schedule of the Diversion Channel will follow the procedure which is specified in the procurement and construction plan, and the construction will be completed within 5 years.

Table 3.5.1 Schedule of Outer Ring Road and Diversion Channel combined project



Source: JICA Study Team

3.6 Project Evaluation

3.6.1 Economic evaluation

(1) Precondition

- The targeted benefit for evaluation comes from the reduction of damage to the assets and the stocks in industrial sectors and household sector (Direct Damage) and the reduction of damage caused by the stop of economic activities and the cost to recover the damaged situation (Indirect Damage). Other kinds of benefit, for example, the reduction of human suffering, option value, etc., are not included. Direct damage of each mesh (2km×2km) is calculated by multiplying "damage rate" in the "Draft of Economic Survey Manual for Water Control Project" published by the Ministry of Land, Infrastructure, Transport and Tourism of Japan, with the assets of the manufacturing sector and the household sector in each mesh estimated from statistics data in Thailand. Direct damage in other sectors than manufacturing sector and household sector and indirect damage in all sectors are estimated by using the damage ratio of the flood in 2011.
- The expected damage reduction (Dm) is the different estimated damage cost obtained from the comparison between the cases whether with or without the presence of the Diversion Channel. The comparisons are made with various scale of floods, namely 2-year, 3-year, 5-year, 10-year, 30-year, 50-year and 100-year floods.

  The estimation procedures are as follows:

  i) Setting of the various probable scale hyetographs

    Actual hyetograph during 2011 flood was considered as the 100-year hyetograph based on the probability analysis using six-month cumulative rainfalls as indicator. Six-month cumulative rainfall is closely related to the flood damage. Then, set up various probable scale hyetographs by adjusting this 100-year hyetograph in smaller figure for various scale of rainfall amount.

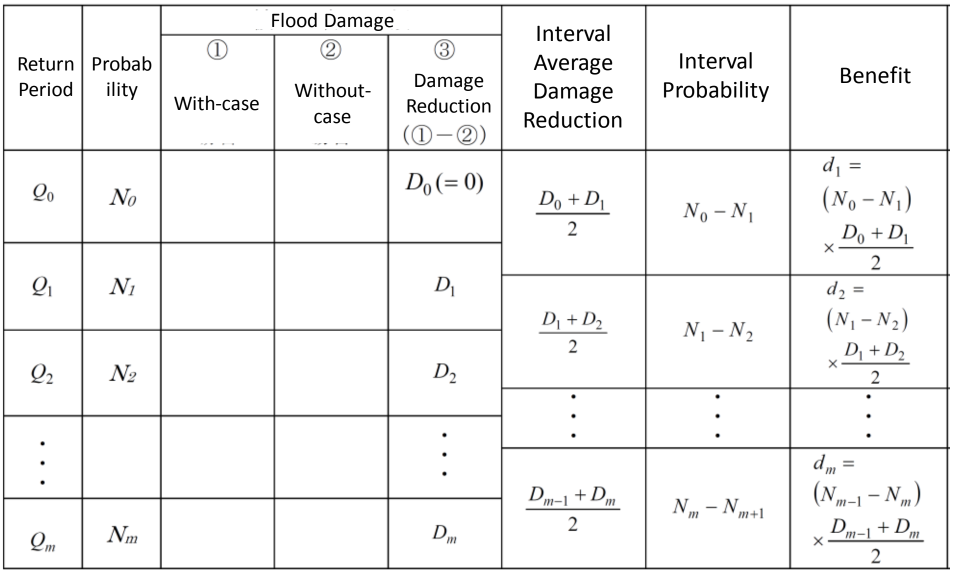
  ii) Run-off/Inundation Analysis

    Input various probable scale hyetograph to the Run-off and Inundation simulation model and calculate inundation area, inundation depth and inundation period depend on the probable scales.

  iii) Estimating the damage costs

    Estimate damage costs in case of various probable scales depend on the inundation area, depth and period.
- The annual average damage reduction (d_m) is calculated from multiplying the interval average damage reduction ($[D_m + D_{m-1}]/2$) with the interval probability of flood occurrence ($N_m - N_{m+1}$). The total damage reduction due to the Diversion Channel is the cumulative total of the annual damage reduction of all intervals.

Table 3.6.1 Benefit calculation table



Return Period	Probability	Flood Damage			Interval Average Damage Reduction	Interval Probability	Benefit
		① With-case	② Without-case	③ Damage Reduction (①−②)			
Q_0	N_0			$D_0 (= 0)$	$\frac{D_0 + D_1}{2}$	$N_0 - N_1$	$d_1 = (N_0 - N_1) \times \frac{D_0 + D_1}{2}$
Q_1	N_1			D_1	$\frac{D_1 + D_2}{2}$	$N_1 - N_2$	$d_2 = (N_1 - N_2) \times \frac{D_1 + D_2}{2}$
Q_2	N_2			D_2	⋮	⋮	⋮
⋮				⋮	$\frac{D_{m-1} + D_m}{2}$	$N_m - N_{m+1}$	$d_m = (N_{m-1} - N_m) \times \frac{D_{m-1} + D_m}{2}$
Q_m	N_m			D_m			

Source: JICA Study Team

- The construction period is 5 years from 2021 to 2015, and any benefit does not occur in the construction period, but the benefit occurs from 2026. The targeted period for evaluation is 40 years from 2021 to 2060, and it is assumed that the benefit and Operation and Maintenance cost will keep occurring even after 2060. Therefore, the residual value to occur is added to the benefit and cost.
- The social discount rate adopted generally in Thailand is 12%, so 12% is adopted also in this project evaluation.
- Economic growth in the targeted period is also incorporated in the calculation.
- The predicted real economic growth rate in Thailand according to IMF’s “World Economic Outlook (April 2017)” is a low 3% from 2017 to 2020 and 3% from 2021 onward as shown in Table 3.6.2.

Table 3.6.2 Prediction of the real economic growth rate of Thailand

Year	2017	2018	2019	2020	2021 and beyond
Real Economic Growth Rate	3.0%	3.3%	3.2%	3.1%	3%

Source: JICA Study Team

Based on the prediction by IMF, the real economic growth rate in the targeted period is assumed to be 3%, and annual benefit and cost for operation and maintenance increase in line with the economic growth.

(2) Benefit evaluation

The flood damage of With-case and Without-case in each return period is shown in Tables 3.6.3 and 3.6.4.

Table 3.6.3 Benefit calculation table: manufacturing sector

Return Period	Occurrence Probability	With-case (Mil THB)	Without-case (Mil THB)	Damage Reduction (Mil THB)	Interval Average Damage Reduction (Mil THB)	Interval Occurrence Probability	Interval Benefit
1-year	1.000	0	0	0	0	0.5	
2-year	0.500	0	0	0	4,484	0.167	747
3-year	0.333	277,133	268,166	8,967	29,483	0.133	3,931
5-year	0.250	523,502	473,504	49,998	53,730	0.100	5,373
10-year	0.100	773,357	715,896	57,461	88,359	0.067	5,891
30-year	0.033	1,174,601	1,055,343	119,258	130,631	0.013	1,742
50-year	0.020	1,303,110	1,161,105	142,005	161,122	0.010	1,611
100-year	0.010	1,539,306	1,359,067	180,239			
						Total	19,295

Source: JICA Study Team

Table 3.6.4 Benefit calculation table: household sector

Return Period	Occurrence Probability	With-case (Mil THB)	Without-case (Mil THB)	Damage Reduction (Mil THB)	Interval Average Damage Reduction (Mil THB)	Interval Occurrence Probability	Interval Benefit
1-year	1.000	0	0	0	0	0.5	0
2-year	0.500	0	0	0	0	0.167	0
3-year	0.333	17	17	0	0	0.133	0
5-year	0.250	0		0	1,657	0.100	166
10-year	0.100	16,485	13,172	3,313	43,025	0.067	2,868
30-year	0.033	144,440	61,704	82,737	82,454	0.013	1,099
50-year	0.020	194,814	112,643	82,171	92,175	0.010	922
100-year	0.010	349,763	247,584	102,179			
						Total	5,055

Source: JICA Study Team

In the benefit evaluation of other sectors than the Manufacturing sector and Household sector, as mentioned already, the ratio of other sectors' total damage to the Manufacturing sector and Household sector's total damage in 2011 flood is used. The estimation formula is shown below;

$$\text{Flood Damage Reduction in Other Sectors than Manufacturing Sector and Household Sector}$$

$$= \frac{\text{Flood Damage in Other Sectors in 2011 Flood}}{\begin{array}{c}\text{Flood Damage in Manufacturing Sector}\\ \text{and Household Sector in 2011 Flood}\end{array}} \times \begin{array}{l}\text{Estimated Flood Damage Reduction by the Diversion Channel}\\ \text{in Manufacturing Sector and Household Sector}\end{array}$$

$$= 0.307 \times \begin{array}{l}\text{Estimated Flood Damage Reduction by the Diversion Channel}\\ \text{in Manufacturing Sector and Household Sector}\end{array}$$

The estimated benefit in other sectors than Manufacturing Sector and Household sector is 13,105 Mil THB.

To summarize above, the total annual benefit from the Diversion Channel run up to 31,774 Mil THB.

(3) Net Present Value (NPV), Economic Internal Return Rate (EIRR), Cost-Benefit Ratio (B/C)

The total project cost, excluding operation and maintenance cost of the Diversion Channel is 132,314, which is assumed to be distributed evenly from 2021 when the land acquisition and construction starts, until 2025 when the Diversion Channel is completed.

From 2026, the operation and maintenance of the Diversion Channel is estimated at 1% of the project cost, 1,323 Mil THB every year. The operation and maintenance cost increase in line with the real economic growth (3% annually).

Meanwhile, the annual benefit of the Diversion Channel, 31,774 Mil THB per year from the beginning of its usage in 2026, and the benefit increases in line with the real economic growth (3% annually). Therefore, the benefit in 2026 is 41,458 Mil THB due to the real economic growth since 2017.

The benefit and cost in the targeted period for evaluation, from 2021 to 2060, is chronologically shown in the Table 3.6.6. The benefit and cost in 2060 include the terminal value since 2061 based on the assumption that the benefit and cost for operation and maintenance occur after 2060; the terminal value of the benefit and maintenance cost is calculated by dividing then by the discount rate (12%).

The Net Present Value (NPV) of the Diversion Channel in 2017 is calculated with the formula shown below; NPV is the sum-up of the difference between the benefit Bn and cost Cn in each year (n) discounted by the years from 2017.

$$\mathrm{NPV} = \sum_{n=2017}^{2060} \frac{B_n - C_n}{(1+r)^{n-2017}}$$

The result of the estimation is shown in the Table 3.6.5; the NPV of the Diversion Channel is 100,345 Mil THB, the EIRR is 20.7%, the B/C is 2.21.

Table 3.6.5 Economic index

Index	Value
Net Present Value (NPV)	100,345 Mil THB
Economic Internal Return Rate (EIRR)	20.7%
Benefit-Cost Ratio (B/C)	2.21

Source: JICA Study Team

Table 3.6.6 Annual benefit and cost

Unit : Mil THB

Year	Benefit			Cost		
	Benefit	Present Value	Residual Value	Benefit	Present Value	Residual Value
2021	0	0		29,784	18,928	
2022	0	0		29,784	16,900	
2023	0	0		29,784	15,090	
2024	0	0		29,784	13,473	
2025	0	0		29,784	12,029	
2026	41,458	14,950		1,489	537	
2027	42,702	13,749		1,534	494	
2028	43,983	12,644		1,580	454	
2029	45,302	11,628		1,627	418	
2030	46,661	10,694		1,676	384	
2031	48,061	9,834		1,726	353	
2032	49,503	9,044		1,778	325	
2033	50,988	8,317		1,832	299	
2034	52,518	7,649		1,886	275	
2035	54,093	7,034		1,943	253	
2036	55,716	6,469		2,001	232	
2037	57,388	5,949		2,061	214	
2038	59,109	5,471		2,123	197	
2039	60,882	5,031		2,187	181	
2040	62,709	4,627		2,253	166	
2041	64,590	4,255		2,320	153	
2042	66,528	3,913		2,390	141	
2043	68,524	3,599		2,461	129	
2044	70,579	3,310		2,535	119	
2045	72,697	3,044		2,611	109	
2046	74,878	2,799		2,690	101	
2047	77,124	2,574		2,770	92	
2048	79,438	2,367		2,853	85	
2049	81,821	2,177		2,939	78	
2050	84,276	2,002		3,027	72	
2051	86,804	1,841		3,118	66	
2052	89,408	1,693		3,212	61	
2053	92,090	1,557		3,308	56	
2054	94,853	1,432		3,407	51	
2055	97,698	1,317		3,509	47	
2056	100,629	1,211		3,615	44	
2057	103,648	1,114		3,723	40	
2058	106,758	1,024		3,835	37	
2059	109,960	942		3,950	34	
2060	113,259	866	7,220	4,068	31	259
Total		183,351			83,006	

Net Present Value	100,345
Cost Benefit Ratio	2.21
Economic Internal Rate of Return	20.7%

Source : JICA Study Team

The EIRR exceeds not only the social discount rate (12%), but also 15% which is required generally for public works in Thailand. Moreover, the B/C is also largely beyond 1.0, so it is concluded that the Diversion Channel is sufficiently efficient socio-economic investment and it is highly feasible as a public works.

3.6.2 Unaccountable benefits in economic evaluation

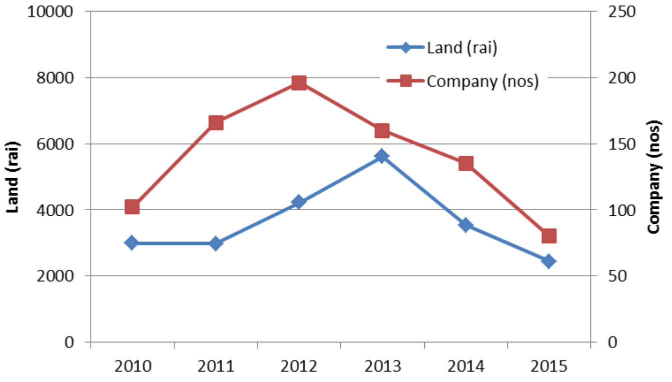
The following damages and negative impacts can be reduced by the project, though it is difficult to evaluate such benefits quantitatively from the economical point of view as is shown in 3.6.1.

- Number of casualties (dead and injuries)
- Spreading damages to surroundings of inundated area
- People's psychological damages due to the flood
- People's anxiety for the possibility of flood damage

It is also expected that the land value of the inundated areas including the surrounding areas will rise according to the improvement of the safety against flood. The following additional effects of the project will lead to the rising of the land value, such as "Development of Industrial Estate and Residential Area" and "Creation of River Front Area".

(1) Development of Industrial Estate and Residential Area

One of the major reasons of JICA MP is to protect the industrial estates around Ayutthaya which suffered severe damage by the flood in 2011. It was expected in JICA MP that the investment to Thailand from other countries including Japan would not stop and the economic development of Thailand would continue sustainably. The Figure 3.6.1 shows the time series of the amount from 2010 to 2015 of newly developed land and the number of new companies which bought the land. Although the amount of new land and new companies each year is slightly decreasing in accordance with the economy of Thailand, we can see the total amount of land and the total number of companies is still increasing.



Source : Annual Report 2012 and 2015, Industrial Estate Authority of Thailand

Figure 3.6.1 Amount of newly developed land and number of new companies which bought the land

According to the recent news article on the industrial estate in Thailand, the development of industrial estate and the companies to buy the land had shifted from the Ayutthaya area to the east coastal area because of the flood disaster in 2011. However, the Ayutthaya areas has been re-evaluated as the suitable area for the industrial estate, since the Board of Investment in Thailand (BOI) has abrogated the "Zoning System[3]" and there has been a lot of water for the factories in Ayutthaya area. It also says that many companies have already

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[3] By this system, the companies which buy the land far from Bangkok can receive more benefit. The benefit varies depending on the distance from Bangkok.

returned to the industrial estate in Ayutthaya area where the flood control measures such as constructing concrete walls were implemented by the companies.

Since this combined project will make the Ayutthaya area to be safe from flooding, and the accessibility will be improved not only to Bangkok but also to Suvarnabhumi Airport and the east coastal areas, more investment to the existing industrial estates and the newly development of industrial estate are expected. It is also expected that the housing development will be promoted around Ayutthaya areas because of this combined project.

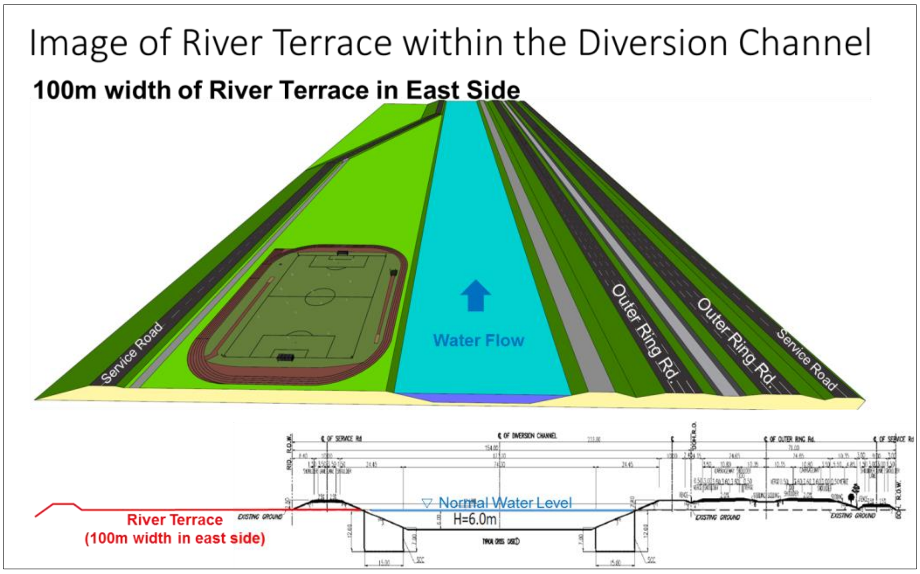
Figure 3.6.2 shows the image of newly developed flood free industrial estate and residential area.

Source : JICA Study Team

Figure 3.6.2 Image of new flood free industrial estate and residential area

(2) Creation of River Front Area

New river front area will be created when this combined project is implemented. The Diversion Channel has a big role to be an environmental buffer zone for the construction of the Outer Ring Road. The Diversion Channel can have a function as a relaxation area for the resident people by placing a green belt and a river terrace. Figure 3.6.3 shows the image of river terrace.



Source : JICA Study Team

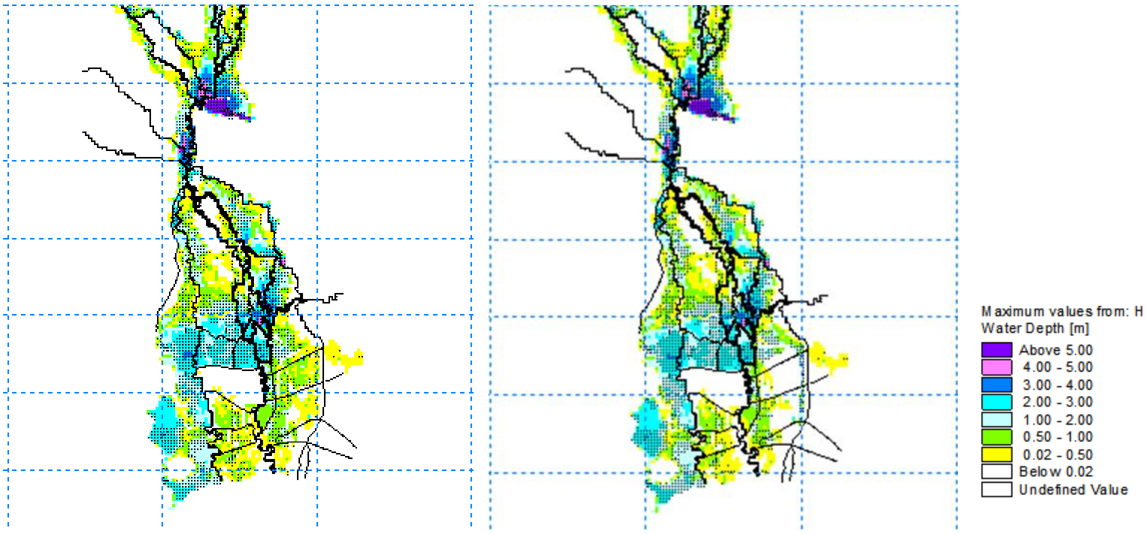
Figure 3.6.3 Image of river terrace

3.6.3 Presentation methods to public

General Economical Evaluation Index such as B/C and EIRR are used for the project evaluation. However, it is said that these indexes are so technical that residents cannot understand its effectiveness. Therefore, some of the methods are proposed to explain benefits of the project

(1) Reduction of Inundated Area

As is shown in the Figure 3.6.4, the change of the inundated area with/without the project is one of the most understandable methods.



Source : JICA Study Team

Figure 3.6.4 Reduction of inundated area (Left: without project, Right: with project)

(2) Perspective Drawing

The perspective drawings such as the drawings shown in the section 3.6.2 are the effective tools to presents the advantages of the project for the residents.

3.6.4 Project Evaluation

As mentioned above, the EIRR exceeds not only the social discount rate (12%), but also 15% which is generally required for the public works in Thailand. Moreover, the B/C is also largely beyond 1, so it is concluded that the Diversion Channel is sufficiently efficient socio-economic investment and it is highly feasible as a public works. In addition, not only the benefit from flood damage reduction, but also some other kind of benefit come from the Diversion Channel and the integrated development of the Outer Ring Road and the Diversion Channel. In addition, not only the benefit from flood damage reduction (reduction of damage to assets and stocks in industrial sectors and household sector (Direct Damage) and reduction of damage caused by the stop of economic activities and the cost to recover the damaged situation (Indirect Damage)), but also some other kind of benefit come from the Diversion Channel and the integrated development of the Outer Ring Road and the Diversion Channel.

- Reduction of human casualties
- Mental relief by the reduction of flood damage
- Active business location owing to the enhanced safety
- Active development activity using excavated soil, for example, development of a safe industrial estate using the excavated soil coming from the construction of the Diversion Channel
- Ecosystem service from the aquatic organism in the biotope formed in the Diversion Channel
- Usage of flood channel as a park, sports facilities
- Agricultural usage of the Diversion Channel for irrigation
- Thailand becomes a leading country for flood control in ASEAN and the world

These kinds of benefit are difficult to calculate quantitatively because of the high uncertainty of occurrence and low robustness of evaluation method. Therefore, the valuation only by the benefit from the flood damage reduction covers one part of the whole benefit of the Diversion Channel, so it can be said that the result of this benefit evaluation is modest, which enhances that the Diversion Channel is highly feasible. However, it is better to evaluate those kinds of benefit if conditions to evaluate are sufficiently prepared: reduction of uncertainty, establishment of a robust evaluation method, etc.

Finally, activating business location in Thailand owing to the flood damage reduction and economic development activities like a development of safe industrial estate using the excavated soil from the construction of the Diversion Channel can contribute to the promotion that the Thai economy becomes the hub of logistics for sustainable economic growth, which can lead to transcend “Central Income Trap” for the Thai economy. It is expected that these sustainable investments to manufacturing sector contributes to make the way to promote Thailand to be a developed country from a semi developed one. Therefore, those additional usage and development should be considered to increase economic impact of the Diversion Channel.

CHAPTER4 RID’S PLAN AND JICA’S OPINION ON RID’S PLAN

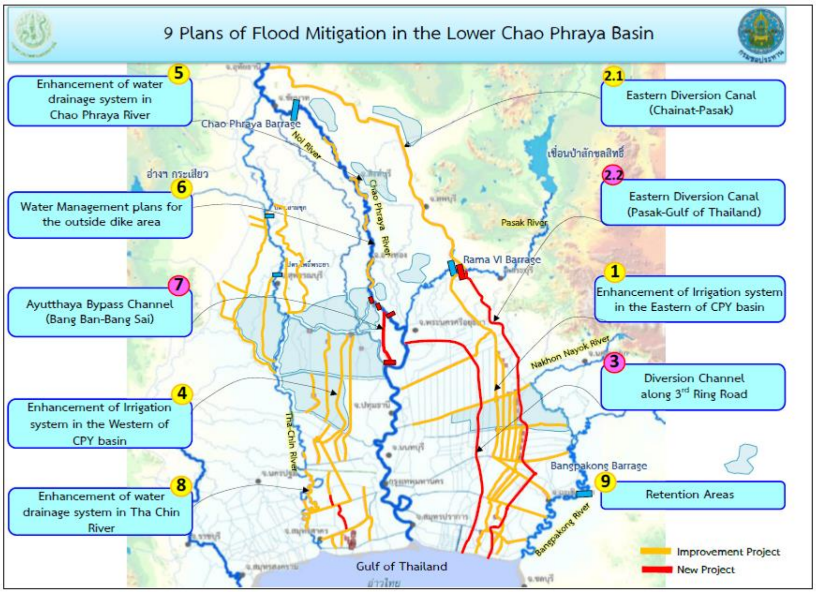
This project has considered immediate implementation of Outer Ring Road Diversion Channel plan based on RID’s request. Meanwhile, as the project progressed RID persisted high priority of the Ayutthaya bypass Channel and the Chainat-Pasak Channel. Additionally RID requested JICA to consider and compare effect of Outer Ring Road Diversion Channel to effect of the Pasak-Gulf of Thailand Channel. It meant that conflict of view between JICA and RID emerged clearly. Following above situation, this chapter introduces overview of RID’s original flood control plan (RID Plan), aside from JICA MP, mentions JICA’s opinion on it.

4.1 RID Plan

4.1.1 Summary of RID Plan

RID has been discussing about flood management taking the flood in 2011 as defense target, including planning of diversion channel on both sides, and has proposed following 9 projects to the Cabinet.

1. Enhancement of Irrigation System in the Eastern of the Chao Phraya River Basin
2-1. Eastern Diversion Channel (Chainat-Pasak (CP))
2-2. Eastern Diversion Channel (Pasak-Gulf of Thailand (PGT))
3. Diversion Channel along the Outer Ring Road
4. Enhancement of Irrigation system in the Western of the Chao Phraya River basin
5. Enhancement of water drainage system in the Chao Phraya River
6. Water Management plans for the outside dike area
7. Ayutthaya Bypass Channel (Bang Ban-Bang Sai)
8. Enhancement of water drainage system in Tha Chin River
9. Retention Areas



Source ：RID Document

Figure 4.1.1 Location of 9 Projects（RID Plan）

Nine projects of RID are judged to be feasible from the viewpoint of the environment and society. Under these projects, RID has set the discharge 3,795 m^3/s in Nakhon Sawan (Station C.2) with assumption of discharge capacity 2,800 m^3/s, which is expected not to cause damages in the downstream of the Chao Phraya River. This concept of distribution of discharge to downstream of rivers or channels is similar to irrigation plans. Incidentally, according to the explanation of RID, the scale of this discharge (3,795 m^3/s) is 25 years probability.

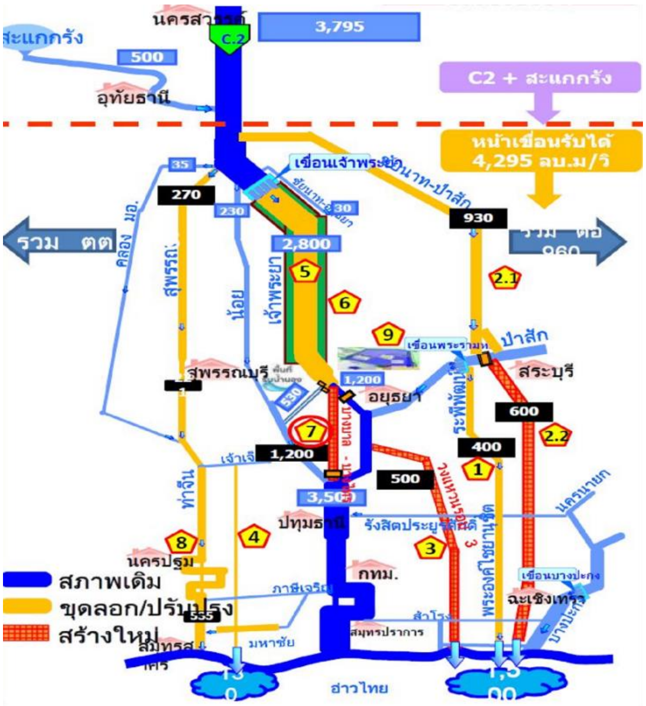


Figure 4.1.2   Discharge distribution in RID Plan

4.1.2 Prioritized Projects in RID Plan

From the RID plan, 4 of the above-mentioned 9 projects are prioritized by RID in following order because of their high budget requirement. They are supposed capable to increase discharge capacity and reduce the peak flood. Summary and current situation for implementation of these project is described below, based on information provided by RID. RID is planning to implement them in the priority order.

Prioritized Project 1: the Ayutthaya Bypass Channel (Bang Ban-Bang Sai) (7)
Prioritized Project 2: the Eastern Diversion Channel (Chainat-Pasak) (2-1)
Prioritized Project 3:the Eastern Diversion Channel (Pasak-Gulf of Thailand) (2-2)
Prioritized Project 4:the Diversion Channel along the Outer Ring Road (3)

(1) Prioritized Project 1：Ayutthaya Bypass Channel (Bang Ban-Bang Sai)

This project can solve bottle-neck problem of the Chao Phraya River at Phra Nakhon Si Ayutthaya province where flood repeats every year. This project was approved in principle by the Cabinet for project preparation phase and under details design phase.

(2) Prioritized Project 2：Eastern Diversion Channel (Chainat-Pasak)

This Channel is a drainage Channel parallel with irrigation Channel. It can reduce flow rate at the upstream of the Chao Phraya Diversion Dam of 800m^3/s. Project can be implemented with no land acquisition or resettlement because of sufficient right-of-way according to RID. Survey and details design work will be conducted in 2019.

(3) Prioritized Project 3：Eastern Diversion Channel (Pasak-Gulf of Thailand)

This project can prevent and mitigate flood from Nakhon Sawan province to Gulf of Thailand. Protected area of this project can cover the area of the Outer Ring Road Diversion Channel dose. Longitudinal slope of Channel bottom is 1:10,000-1:25,000 so that water can be drained by gravity. Besides, water flow in and out can be well controlled because the project is equipped with regulator including the Chao Phraya Diversion Dam, and the Pasak Diversion Dam (the New Rama VI diversion dam). This project can reduce peak flood both in the Chao Phraya River and the Pasak River. Therefore it can be used more frequently than the Outer Ring Road Diversion Channel. Project cost and compensation of this project is lower than the Outer Ring Road Diversion Channel project, which is supposed to be feasible for investment with B/C ratio of 1.49 and EIRR of 17.22%. F/S and EIA have been completed. (However, RID did not provide any evidence for these conclusion.)

(4) Prioritized Project 4：The Outer Ring Road Diversion Channel

The Outer Ring Road Diversion Channel Project, which is under preliminary F/S together with JICA Study Team, is considered as the 4th one. Next step, RID will propose for implementation after the Pre-F/S.

4.2 JICA’s Opinion

Following issues on RID’ plan are pointed out by JICA.

i. Concerned issues of RID Plan

ii. Comparison of economic advantage between “the Outer Ring Road Diversion Channel (DC)” and “Chainat-Pasak Channel (CP) with Pasak-Gulf of Thailand (PGT)”

iii. Correct Order of project implementation

4.2.1 Concerned issues of RID Plan

(1) Concerned issues of the 9 projects

Concerned issues of the 9 projects are pointed out as follows.

- Definition of target discharge (Basic Flood Discharge)

There is no study process for defining "Basic Flood Discharge" such as:

- Defining target rainfall
- Defining target flood
- Assuming no overflow from the river upstream than observation point
- Design discharge distribution to the flood control facilities

There is no study process for defining “Design Discharge Distribution” such as:

- Estimation of discharge capacity of the river
- Against Design Flood, considering the optimal place for facilities such as river improvement, dams, detention area, and drainage channels
- Set the optimal discharge allocation for each flood control facility

A flow chart of flood control planning in Japan (Figure 4.2.1) is provided for RID to understand these two concerned issues.

- **Comprehensive project evaluation of RID nine projects**
- Costs benefit ratio for the whole nine projects has not been calculated although some projects’ cost benefit ratios have been calculated. The nine projects have been submitted to the Cabinet without evaluation for the necessity of the whole nine projects.

The nine projects are selected only by easiness of implementation without technical study process. And values of RID’s design discharge are simply sum-up. What is worse, it is impossible for us to judge how large the target flood scale is, or by which means flood can be controlled, nor whether the prioritized project is the optimal one, because there is no comprehensive economic evaluation on the 9 projects.

In one word, it is far from a flood control plan that is based on engineering approaches.

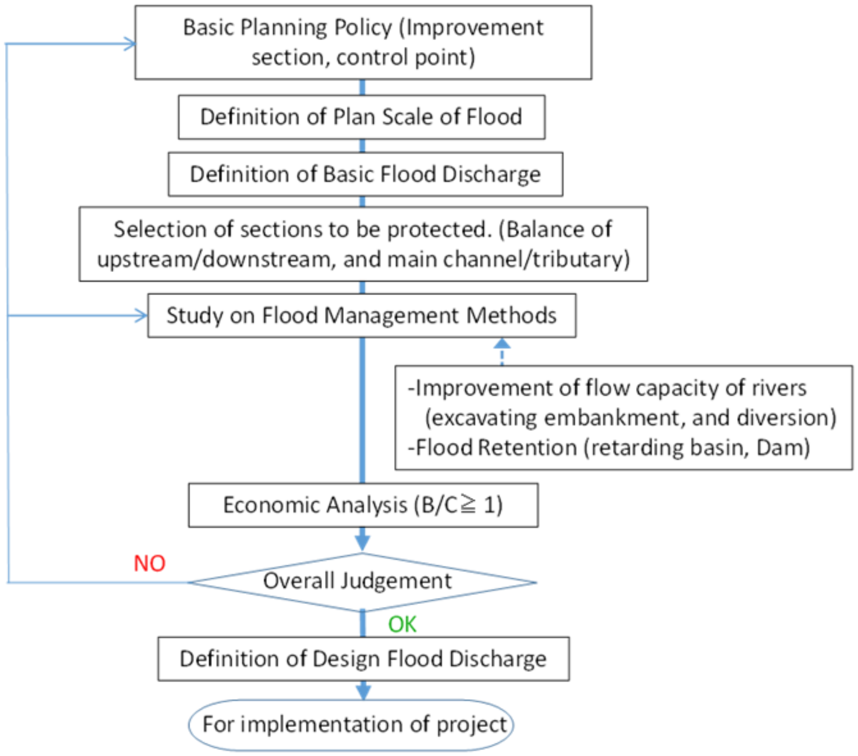


Figure 4.2.1 Flow chart of flood control planning in Japan

JICA Master Plan is the result of study according to the above procedure.

Key points are shown below.

i. Plan scale: 2011 flood scale (= 100-year return period)

ii. Most effective plan with protected area and controlled inundation area, considering asset distribution in the whole river basin

iii. Combination with "Improvement of dam operation" and "Dike heightening in weak part of downstream of the Chao Phraya River" which are low cost, but early and highly effective

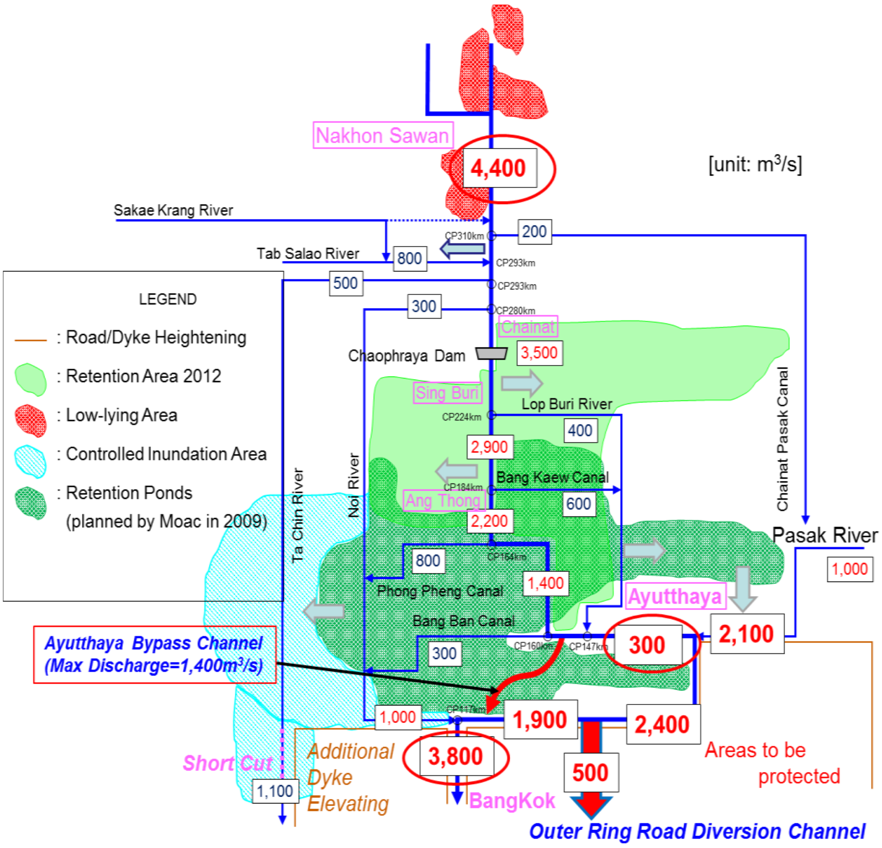


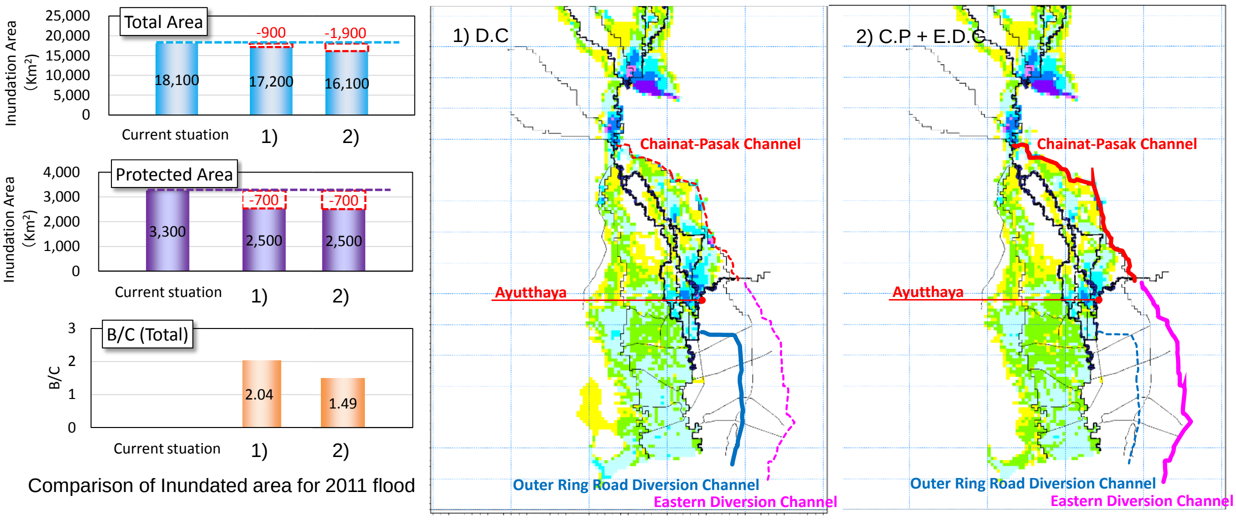
Figure 4.2.2 JICA Master Plan

(2) Comparison of Economic Advantage between DC and CP + PGT

The following is a comparison of Economic Advantage between DC and CP + PGT:

- Economic evaluation on DC: B/C=2.04, EIRR=19.5% while Economic evaluation on CP+PGT: B/C=1.49, EIRR=13.9%. DC is better than CP+PGT in economic evaluation.
- As an estimated result, DC may have shorter construction period, and mitigate the inundation at earlier stage, thus the DC should be implemented with a higher priority.
- Besides, as pointed out at meetings, "Improvement of dam operation" and "Dike heightening in weak part of downstream of the Chao Phraya River" have a better and quicker effect with less cost which should be implemented with the highest priority.

In a nutshell, with shorter construction period and faster effect, DC is far more effective economic rather than CP+PGT.



Comparison of Inundated area for 2011 flood

※Both cases are simulated based on the conditions that "Improvement of dam operation" and "Dike heightening in the weak part of downstream of the Chao Phraya River" are implemented.

※ Both cases are the combination of constructing Ayutthaya Bypass

Figure 4.2.3 Project effectiveness (inundation mitigation)

Table 4.2.1 Project effectiveness (economic view)

Alternative	**Length (km)**	**Cost (Mil. THB)**	**Construction Period (Year)**	**B/C**
1)The Outer Ring Road Diversion Channel	111	165,695	5	2.04
2)Eastern Diversion Channel Chainat-Pasak＋Pasak-Gulf of Thailand）	270	293,487	15	1.49

Cost includes the cost for Ayutthaya Bypass

(3) Correct Order of project implementation

1) Concerned issues of implementing the Ayutthaya Bypass (AB) prior to DC

JICA Study Team has pointed out following concerns for many times; nevertheless RID is looking forward to implement AB and PGT first.

- It is common sense to implement projects from the downstream side.
- Under current condition of river and facilities, it is definitely inappropriate to implement AB or PGT before DC.

If AB project is completed without improving dam operation or dike heightening in weak part of downstream of the Chao Phraya River first, huge problem will happen when the similar scale of 2011 flood strikes again. As shown in Figure 4.2.4, water level near the diversion point of AB will decrease, however, in the Chao Phraya River it will be even higher than that before the construction of AB, which makes it **more dangerous**

for the downstream area than 2011. In another word, once implementing project is in wrong order, RID is going to **expose people living downstream to worse situation**.

RID explained that this is not a problem since gate will be installed on AB and it will be closed during large-scale flood. However, it is doubtful if they can successfully close the gate in the situation that the flood is occurring in upstream of the Ayutthaya Bypass. It should be proved based on practical situation instead of unrealistic logic.

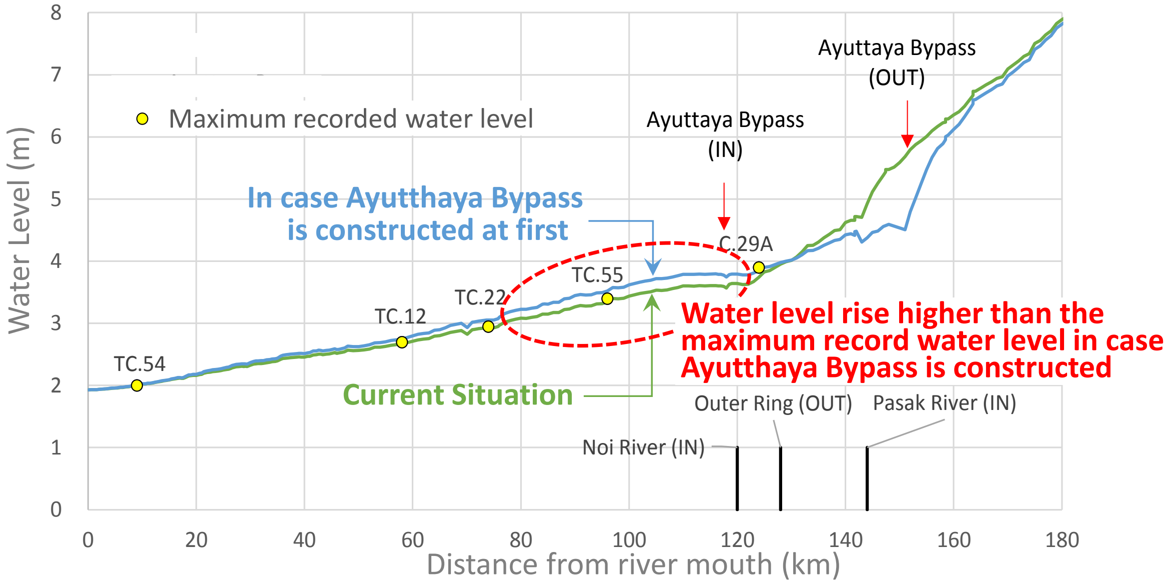


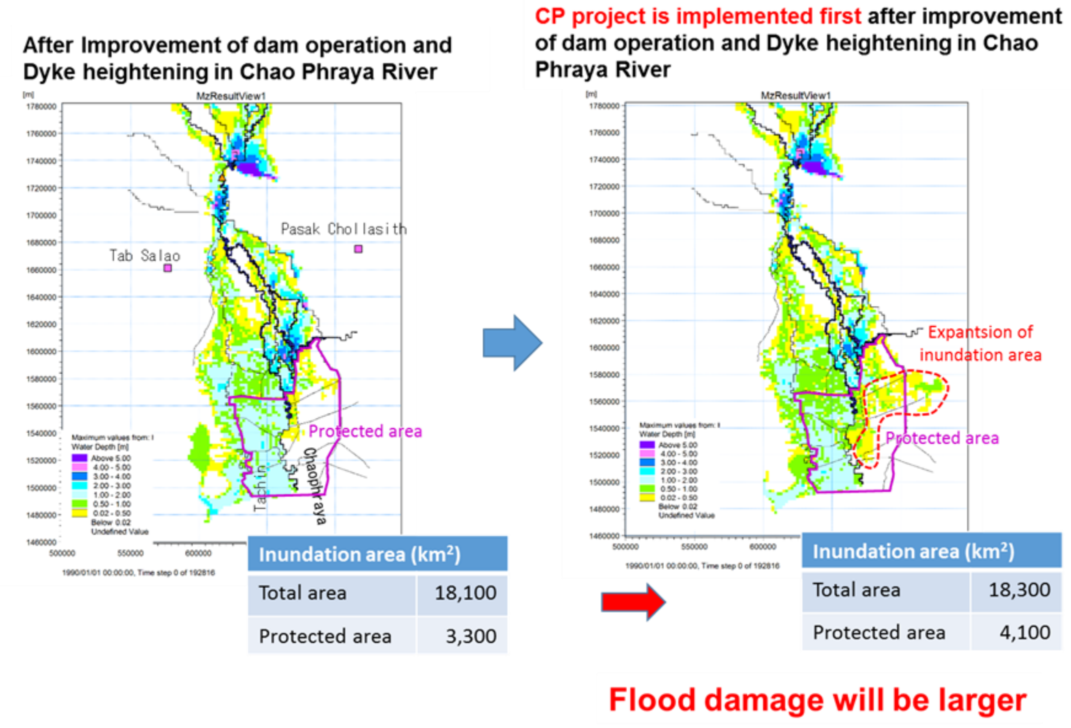
Figure 4.2.4 Comparison of water level for 2011 Flood with and without the Ayutthaya Bypass

2) Concerned issues of implementing CP prior to DC

Concerned issues of implementing CP prior to DC is described as follows.

Figure 4.2.5 indicates the results of inundation analysis. The analysis assumes the situation where the Chainat-Pasak Channel is completed first after “Improvement of dam operation” and “Dike heightening in weak part of downstream of the Chao Phraya River”

If the similar scale 2011 floods occurs, flood damages can be mitigated in some areas by the channel. However, flood will occur in areas where were not flooded before. The downstream basin will suffer serious flood damages more than without the channel. Therefore, the project should not be implemented first.



After Improvement of dam operation and Dyke heightening in Chao Phraya River

CP project is implemented first after improvement of dam operation and Dyke heightening in Chao Phraya River

Inundation area (km^2)	
Total area	18,100
Protected area	3,300

Inundation area (km^2)	
Total area	18,300
Protected area	4,100

Flood damage will be larger

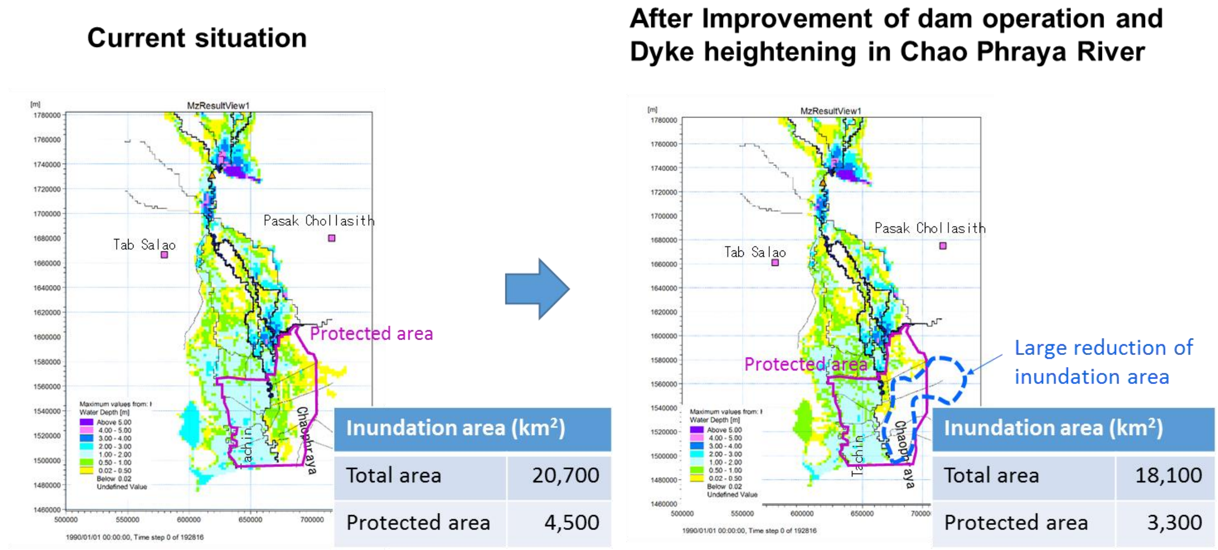
Figure 4.2.5 Comparison of inundation area

3) First priority project that should be implemented by RID

RID should implement following projects first that RID can lead to implement. These projects can mitigate inundation area largely with a relatively small cost.

- Improvement of dam operation during flooding time
- Dike heightening in weak part of downstream of the Chao Phraya River

The effect of these projects against 2011 flood is shown in Figure 2.4.6. Above two projects have been proposed in JICA Master Plan which RID should give highest priority.



Current situation

After Improvement of dam operation and Dyke heightening in Chao Phraya River

Inundation area (km^2)	
Total area	20,700
Protected area	4,500

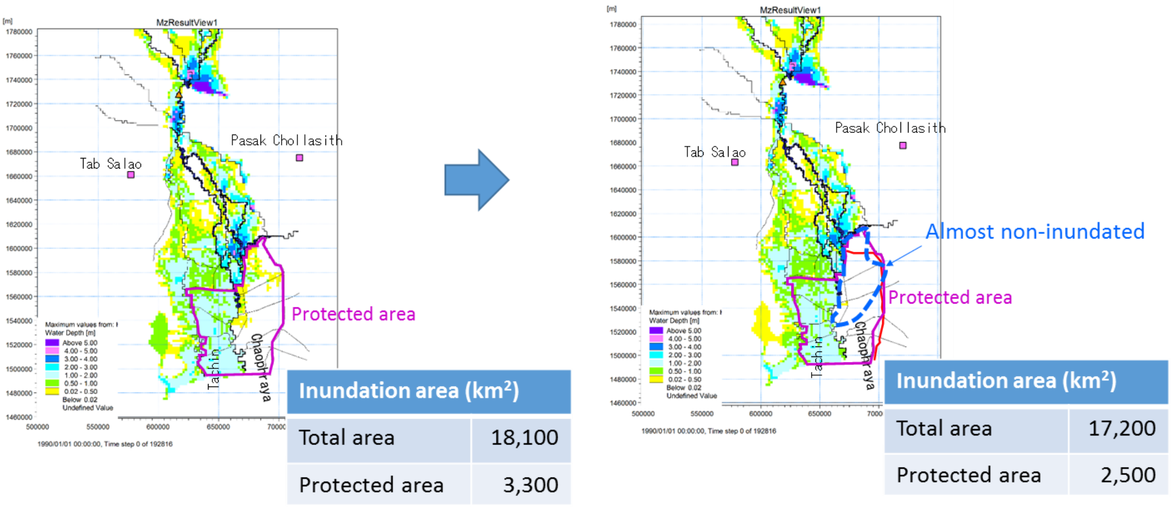
Inundation area (km^2)	
Total area	18,100
Protected area	3,300

Figure 4.2.6 Effect of improvement of dam operation and dike heightening in downstream of the Chao Phraya River

4) Project effect of Diversion Channel and Ayutthaya Bypass

RID should implement DC Project after completion of “Improvement of dam operation” and “Dike heightening in weak part of downstream the Chao Phraya River” as described in 1). By completing DC together with the Ayutthaya Bypass, the inundation area will be greatly reduced. These effect is shown in Figure 4.2.7.

However Ayutthaya Bypass should not be implemented prior to the completion of DC.



After Improvement of dam operation and Dyke heightening in Chao Phraya River

Inundation area (km^2)	
Total area	18,100
Protected area	3,300

After completion of DC and AB addition to the condition in the left figure

Inundation area (km^2)	
Total area	17,200
Protected area	2,500

Figure 4.2.7 Effect of theDiversion Channel and the Ayutthaya Bypass

4.2.2 Economic comparison

(1) Target index of economic comparison

Benefit over Cost (B/C) and Economic Internal Rate of Return are selected as target index to explain JICA Study Team’s plan is the most appropriate flood management plan for the Chao Phraya River.

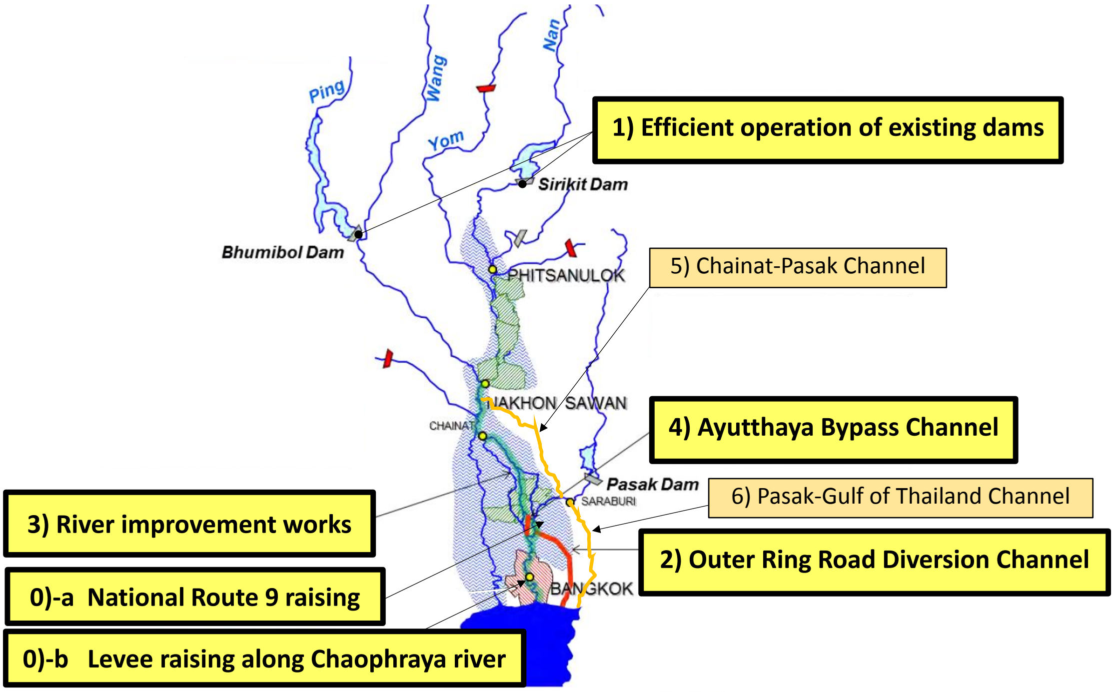
<Case 1>: DC and AB are implemented which is supposed as the highest priority by JICA Study Team

<Case 2>: AB and PGT (Chainat-Pasak and Pasak-Gulf of Thailand) are implemented as prioritized by RID

Table 4.2.2 Comparative case of cost benefit analysis

	<Case 1>		<Case 2>	
	Before	After	Before	After
0)-a Heightening the National Route 9	●	●	●	●
0)-b Heightening the dike the Chao Phraya River	—	●	—	●
1) Improvement of operation rules of existing dam	—	●	—	●
2) Construction of the Outer Ring Diversion Channel	—	●	—	—
3) River improvement works (Tha Chin River)	—	—	—	—
4) Construction of Ayutthaya Bypass Channel	—	●	—	●
5) Widening the Eastern Diversion Channel (Chainat-Pasak)	—	—	—	●
6) Construction of Eastern Diversion Channel (Pasak-Gulf of Thailand)	—	—	—	●

Source : JICA Study Team



Source : JICA MP

Figure 4.2.8 Candidate area for implementing measures against floods

(2) Cost benefit analysis

Cost Benefit Ratio of JICA proposed project that includes constructing the Outer Ring Road Diversion Channel and the Ayutthaya Bypass is 2.04 and Economic Internal Ratio of Return (EIRR) of this project is 19.5%. In contrast, Cost Benefit Ratio of RID recommended project that includes three prioritized projects (Constructing the Ayutthaya Bypass, Widening the Chainat-Pasak Channel and Constructing the Pasak-Gulf of Thailand Channel) is 1.49 and EIRR of this project is 13.9%.

CHAPTER5 RECOMMENDATION AND FUTHER STUDIES

5.1 Recommendation for additional survey

The recommendations and further studies regarding the development of the Outer Ring Road and Diversion Channel combined project by RID can be summarized as follows.

- Recommendations on considerations and issues to be addressed with additional geological surveys.
- Considerations regarding the detail and comprehensive design and construction methods for the Outer Ring Road and Diversion Channel.

5.1.1 Required items and consideration regarding geological survey by RID

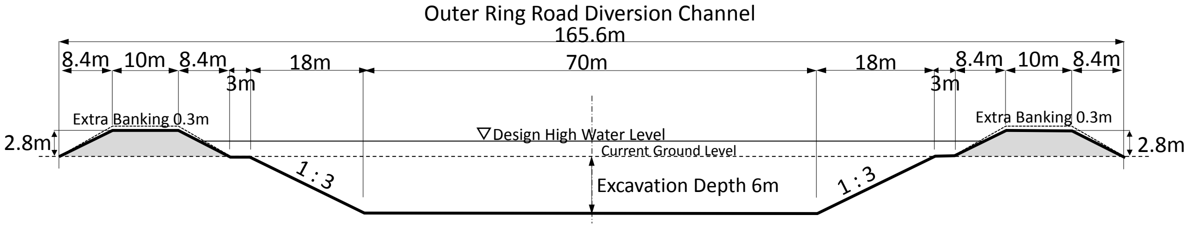
(1) Geological survey

The current study covers the basic design for a feasibility assessment of the Outer Ring Road and Diversion Channel. The final and the detail design of the Outer Ring Road and Diversion Channel will require a more comprehensive geological survey. Accordingly, there is a possibility of changes in the design of the road and the channel. The changes in the design may affect the project cost as follows.

1) The Outer Ring Road Diversion Channel

(a) North part (Embanking part) 36-km long

- The recalculated settlement of the embankment may require extra-banking.

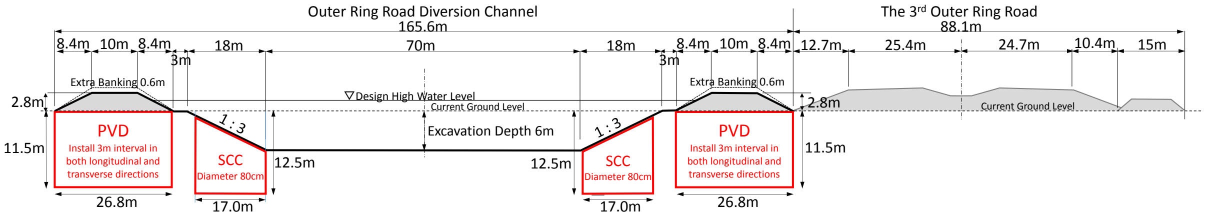


Source : JICA Study Team

Figure 5.1.1 Standard cross section of the Diversion Channel (Northern part)

(b) Central part (SCC and PVD will be installed in this part) 32-km long

- Required area, installation depth, installation width and installation position of SCC (Soil Cement Column) may be redesigned.
- Installation depth and installation position of PVD (Prefabricated Vertical Drain) may be redesigned
- The recalculated settlement of the foundation ground due to preloading may require extra-banking.
- Mixing ratio of clay and sand may be redesigned.

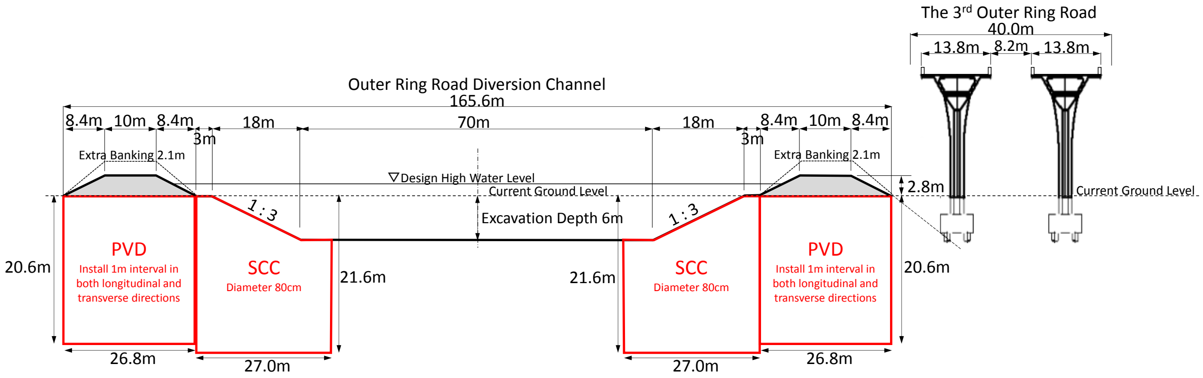


Source : JICA Study Team

Figure 5.1.2 Standard cross section of Diversion Channel (Central part)

(c) South part (SCC and PVD will be installed in this part) 43-km long

- Installation depth, installation width and installation position of SCC may be corrected
- Installation depth and installation position of PVD may be corrected
- By reviewing settlement by pre-loading, extra-embanking may be corrected



Source : JICA Study Team

Figure 5.1.3 Standard cross section of the Diversion Channel (Southern part)

2) The Outer Ring Road (East section)

According to the results from the comprehensive geological survey of the Outer Ring Road (East section), there may be considerable changes in the detail design. Therefore, the final project cost can considerably differ from the current cost estimation. The possible changes in the detail design due to the comprehensive geological survey can be summarized as follows.

(a) Elevated Section（13.322 km：STA 83.790 - STA 97.112）

- The length of elevated section may be modified.
- Pile length may be modified.

(b) Pre-loading and PVD Section（59.51 m : STA 24.280 - STA 83.790）

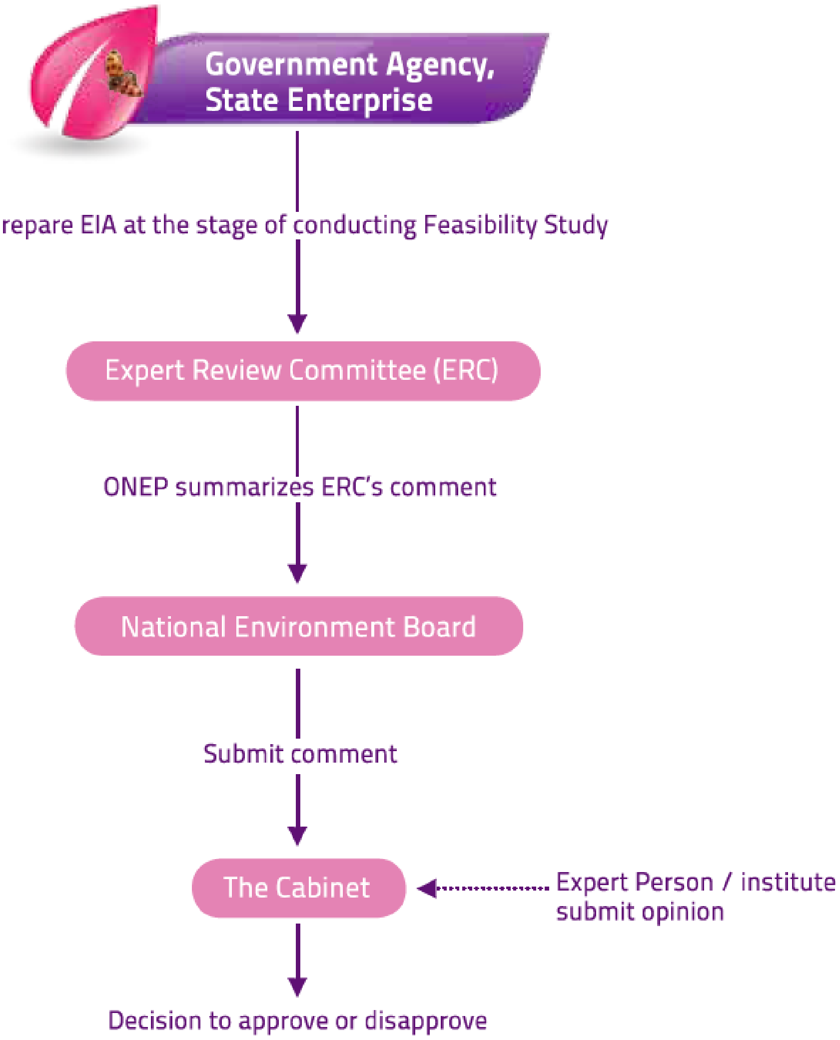
- The depth and interval of PVD may be modified.
- The amount of embankment may be changed because of the reducing settlement due to pre-loading.
- Mixing Ratio for purchased sand and mixing ratio for cement/lime may be modified

(c) Surcharge Section（24.28 km：STA 0.000 - STA 24.280）

- The transportation plan for the embankment material may be modified after the assessment of the amount of suitable soil from the excavation of the diversion channel.

(2) Natural and social environmental survey

In accordance with the “National Environment Quality Act (NEQA, 1992)”, RID have a duty to prepare the Environmental Impact Assessment report (EIA report) during the feasibility study (FS) stage and submit the EIA report to the National Environment Board (NEB) for its review and comments, after which the EIA report is submitted to the Cabinet for its consideration. When the EIA report is approved by the Cabinet, the official legally empowered committee grants permission accordingly and the permission be granted to RID. Simultaneously the public meetings takes place at least twice (1) at the stage of scoping the EIA study and (2) at the stage of drafting the EIA report. Therefore, shortening of the duration of FS and EIA of the Diversion Channel project can be sought by employing several EIA consultant firms and hold public meeting at several provinces around the same time.

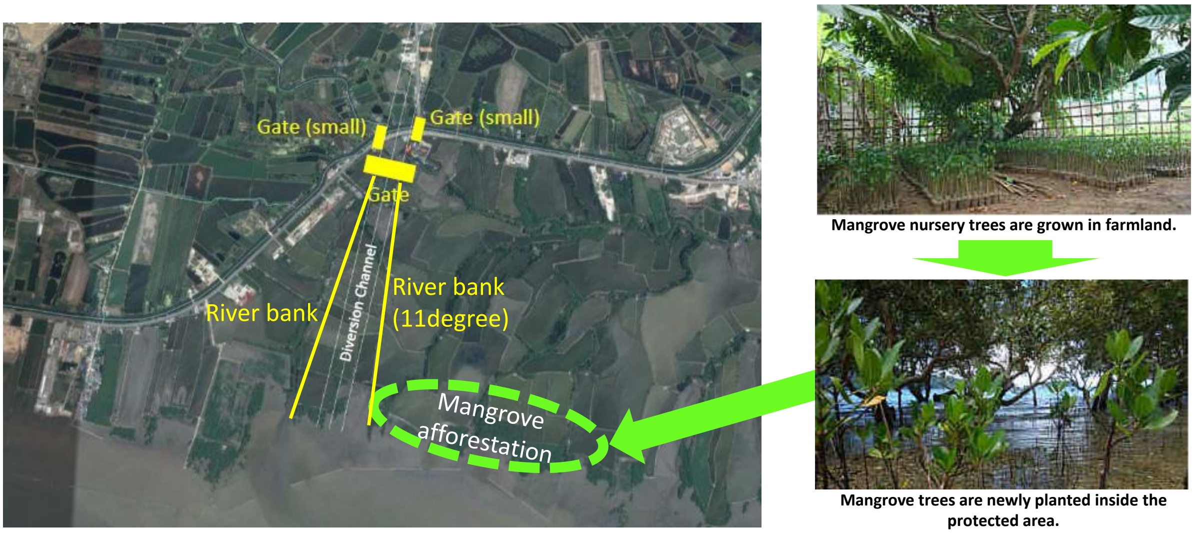


Source : Environmental Impact Assessment in Thailand, 2013, ONEP

Figure 5.1.4 Approval process for projects or activities required the approval of the Cabinet

1) Natural environment

Mangrove within Inner Gulf of Thailand is designated as Thai national forest reserve (August, 2000) The Cabinet Resolution) and wetland within Inner Gulf of Thailand is nominated for registration at The Convention on Wetlands (Ramsar Convention). For the purpose of conservation and maintenance of mangrove and wetland along the coastal area, afforestation and restoration of mangrove at the periphery of outlet of the Outer Ring Road Diversion Channel is necessary.



Mangrove nursery trees are grown in farmland.

Mangrove trees are newly planted inside the protected area.

Source : JICA Study Team

Figure 5.1.5 Image of compensatory approach of mangrove conservation

Compensatory approach of equivalent area of mangrove afforestation and restoration is considered for unavoidable cutting down of existing mangrove trees around the outlet of the Diversion Channel. Until now, any precious species of animals and plants are not found in the surrounding areas. However, in case any precious species are newly found in the future, conservation measures are necessary and need to be studied.

2) Social environment

In terms of social environment (involuntary resettlement, cultural heritage, etc.), in this survey a comparison analysis of the most appropriate alignment of the Outer Ring Road Diversion Channel is conducted and decided in order to minimize the involuntary relocation. In the feasibility study, a consideration is needed on the following possible social environmental impacts and mitigation measures due to the Diversion Channel.

< Minimization of land acquisition area and involuntary relocation number >

Optimization of the Diversion Channel alignment

< Promotion of re-establishment of the relocated residents >

Execution of appropriate compensation plan for properties (land, house, building, tree, etc.) Resettlement of residential areas

< Conservation of historical and cultural heritage >

Optimization of the Diversion Channel alignment

Important properties that should be considered at the planning stage of Outer Ring Road Diversion Channel is shown in Table 5.1.1.

Table 5.1.1 Important properties to be considered before the Diversion Channel construction

No.	Community/ Facility	Province	District	Subdistrict
1	Smile Land & House Village	Phra Nakhon Si Ayutthaya	Bang Pa-In	Kung Lam
2	Somwang Sub Muen Saen Village			Sam Ruean
3	Ban Chang		U-Thai	Ban Chang
4	Liab Khlong Hok Community		Wang Noi	Lamtasao
5	Liab Khlong 27 Community			Hantaphao
6	Liab Khlong 26 Community			Khao Ngam
7	Khao Ngam SAO Office			
8	Wat Pakhlong 11	Pathum Thani	Nong Suea	Bung Kasam
9	Ban Suan Si Pathum			Bung Ba
10	Ban Bung Sanan		Thanyaburi	Bung Sanan
11	Ban Ua Athon Pathumthani			
12	Thamle Thong Community		Lamlookka	Bung Thonglang
13	Ban Khlong Sib	Bangkok	Nong Jok	Khlong Sib
14	Ban Lam Chedi			
15	Temsiri Park			Khu Fang Nua
16	Lam Hin Police Station			
17	Nong Jok Community (NHA)			
18	Bayan 2 Village	Bangkok	Nong Jok	Khu Fang Nua
19	Darussalam Mosque			Khok Faed
20	Darussalam Foundation			
21	Erua Mosque School			
22	Nanthawan Bayan Village			
23	Al-Amiah Cemetery			
24	Ban Lam Erua			
25	Sue Trong Suwinthawong Village			Lam Phakchi
26	Watthana Village			
27	Watthana 2 Village			
28	Soi Kheha Chumchon Chalong Krung			
29	Wat Lamphra-ong Community			
30	Lamphakchi School			
31	Lamphakchi Children Dev. Center			
32	Orchid Ville	Samut Prakan	Bang Sao Thong	Bang Sao Thong
33	Bang Sao Thong Residential Area			

Source : JICA Study Team

5.1.2 Consideration for detailed design and construction

(1) Confirmation of stability by the Finite Element Method (FEM) Analysis (Elasto-Viscoplastic Analysis)

For the construction stage of combined structure, the case of the "Suvarnabhumi Airport Drainage Channel Project" is a good reference because the structure of excavated channel with berm roads are similar to the Outer Ring Road Diversion Channel. The conceptual design for the "Airport Drainage Channel", which was divided into 3 lots including 2 upstream drainage sections and 1 downstream pumping station section, was completed by RID, and implementation design was completed by each Contractor, under the Design-Build contracts for 3 sections. Professor Warakorn Mairaing, Kasetsart University, who has intensive experience and supervised number of projects constructed on very soft Bangkok Clay, sheared his experience of the “Suvarnabhumi Airport Drainage Channel Project” to the JICA study team during the visit to his office on several occasions regarding the construction of the combined project. His valuable experience on several important topics can be summarized as follows.

< Excavation of the Drainage Channel >

The depth of the drainage channel was 3 m with road embankment on both sides with a height of 1.0 m to 1.5 m. For the slope strengthening during excavation work, a Soil Cement Column method was used. It is considered that any heavy equipment, such as excavators and dump trucks, shall not work on the installed SCCs’, so the SCCs’ will never get damaged. The excavators were positioned in the middle of the width of the channel and temporary roads were constructed in the middle of the channel for the dump trucks movement. Consequently, the SCCs will not be damaged and will prevent slope failure.

< Characteristic of Soft Clay during Construction >

The main excavated soil for the "Suvarnabhumi Airport Drainage Channel" was very soft clay so called the "Bangkok Clay". The Bangkok Clay has high sensitivity ratio which easily loose its share strength and trafficability after mingled, therefore heavy equipment such as bulldozers could not be used in the drainage channel. In addition, the creep phenomena, movement of time-dependent, of soft ground was observed immediately after excavation of the drainage, and three weeks later, the deformation of the soft clay causes some slope failures for every three lots despite the slope protection by SCCs. The monitoring results show the failure mechanism like this; Soft clay and SCCs will be deformed by creep phenomena with the same speed up to around 40 mm, then SCC was broken firstly because of stress concentration on SCCs. After the SCCs were broken, the creep phenomena of soft clay continued and deformed the ground, then finally, the soft clay ground had a slope failure at the deformation of around 150 mm. Thus, the limit equilibrium method may be the risky design method as the slope stability analysis for these soft grounds because the method is based on the assumption of that the largest share strengths of SCCs and soft grounds work together at the same time.

< Design and Construction Planning for Excavation of Drainage Channel >

In order to prevent slope failure caused by creep phenomena, the original designs were changed as follows.

- Improvement ratio increased up to 30% from the original design. The original design was based on using limit equilibrium method for slope stability analysis.
- The slope stability analysis by limit equilibrium method may give underestimated results. Therefore a FEM elasto-plastic analysis was introduced to represent the soft ground behavior and instruments such as inclinometers and piezo-meters were installed to monitor and control ground deformation within 40 mm.

In addition, the excavated ground was planned to be stabilized by 1 - 1.5 m deep water in the excavated channel in order to prevent slope failure due to creep phenomena. To provide this depth of water in the excavated channel, dikes were made every 200 m interval and within 2 weeks, water was poured between the dikes just after the completion test for excavation was satisfactory (if pouring of the water occur more than three weeks later after the excavation, the creep failure may occur).

< Remained Soil Disposal >

Generally the excavated soil from the irrigation channel is the property of RID. However, in the case of "Suvarnabhumi Airport Drainage Channel Project", the remained soil by excavation was sold to each contractor, and the amount of the sold price was deducted from the contract amount for each section. The contractor ~~had~~ sold the excavated soil to developers and general firms and it is considered that all the remained soil had been sold out, As for the dumping area, the embanked ground will be stable after one year and can be utilized.

Furthermore, it might be essential to apply FEM Analysis (Elasto-Viscoplastic Analysis) to simulate ground movement and to study how to deal with residual excavated soil during the detailed design and implementation planning stage. In addition, for this kind of big project, it is important to make a pilot project prior to start of the main project and to monitor actual behavior of the soft ground after excavation and embankment works by instruments such settlement plats, inclinometers and piezo-meters. The data from the pilot project are used are used to increase accuracy of FEM analysis by reviewing the parameters regarding creep phenomena of the soft ground. Consequently, an accurate analysis will provide stability of the Outer Ring Road and the Diversion Channel during construction stage.

(2) Necessity of determination of irrigation facilities dimension

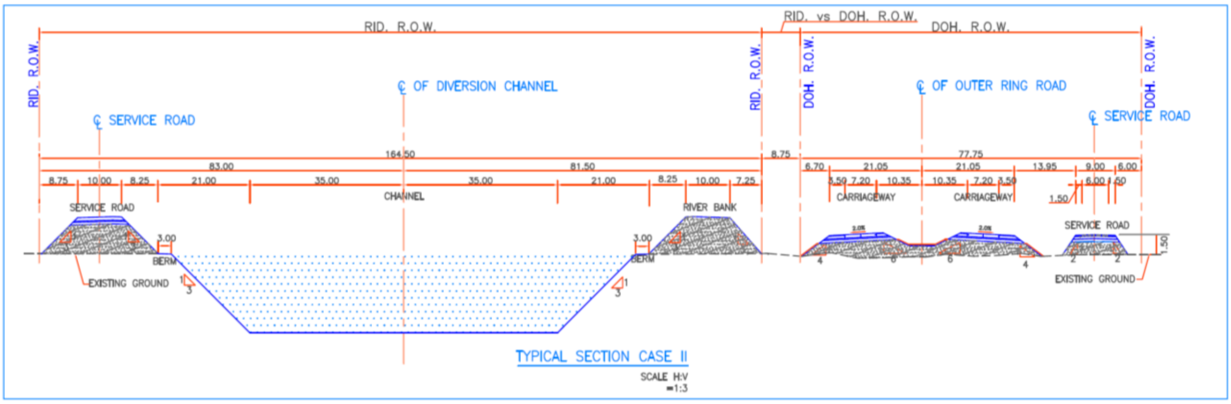
Diversion Channel crosses the existing irrigation channels at 14 sites. At the crossing with irrigation channels, siphons are planned to be constructed. In the detail design, water utilization conditions should be defined clearly and structural design should be implemented.

(3) Optimization of the height of road embankment

The most drastic cost savings for the combined structure of road and diversion channel may be achieved if the height of road embankment is reduced. The height of pavement surface was 3.0 to 3.5 m higher than the ground level in DOH FS (2009). The pavement surface height was set to be 2.0 m higher that the 100-year return period flood level. Therefore, if the design flood level can be controlled and reduced by applying a combined structure, the pavement surface height of the Outer Ring Road can be reduced. The estimated cost down effect is as follows.

- Project Cost for Combined Structure (without reducing embankment height): 54,950 Mil. THB
- Project Cost for Combined Structure (with reducing embankment height) : 50,546 Mil. THB (Savings: 4,404 Mil. THB)

However, on the above estimation, the section where the height of road embankment can be reduced is limited to the south section, starting from Interchange-4. In this section, the Diversion Channel is located on the east side of the Outer Ring Road.



Source : JICA Study Team

Figure 5.1.6 Standard cross section of the Outer Ring Road and Diversion Channel (with reducing embankment height: 1.5 m)

(4) Experimental construction for channel excavation

The difficulty of channel excavation in soft ground is well known in Thailand from the experience of the construction of the Suvarnabhumi Airport Drainage Channel. Therefore, a set of countermeasures are suggested such as stabilizing the ground with SCC before excavation to prevent slope failure, setting the inclination of the excavation slope to be 1:3 and placing excavation machines inside the channel, and waiting for the slope to stabilize after excavating every 1 m. These set of countermeasures can be verified through the monitoring of an experimental construction of channel excavation.

(5) Experimental construction to verify the possibility for embanking material

Approximately 58 million m^3 of soil is supposed to be excavated during the construction of the 110-km long Diversion Channel. One of the important cores of our proposal is to utilize these soft soil, so-called Bangkok Clay, as embanking material by mixing it with purchased sand. 4 levels of mixing method are supposed, namely stockpile (level 1), stabilizer mixing (level 2), and plant mixing (level 3 & 4). However, suitability of each method needs to be verified in experimental construction since the soil property varies in regions as well as mixing ratio.

(6) Necessity of study regarding remained soil disposal

Approximately 60 million cubic meters of excavated soil will be generated by Diversion Channel construction work. Therefore, the measures to reduce costs by using excavated soil in North and Central part as material of embankment were considered. On the other hand, excavated soil in South part will not be useful for the embankment material. In such a case, excavated soil should be disposed. According to the information in Thailand, excavated soil will be available for sale. However, because the amount of excavated soil is very large, it is necessary to consider how to deal with these large amount of excavated soil.

(7) Possibility of simultaneous construction in 55 sections

In order to complete the construction of the 110km-long Diversion Channel in 5 years, one prerequisite is having simultaneous construction in 55 sections (each section is 2km long) with approximately 18,000 machines and trucks operating when peak. We have generally checked the registered amount of machines around Bangkok as well as the possibility to procure them in future, however, a further survey about contractors and their machines is essential to ensure finishing construction in time.

(8) Necessity of study regarding impact to the channel crossing structures and facilities near the channel

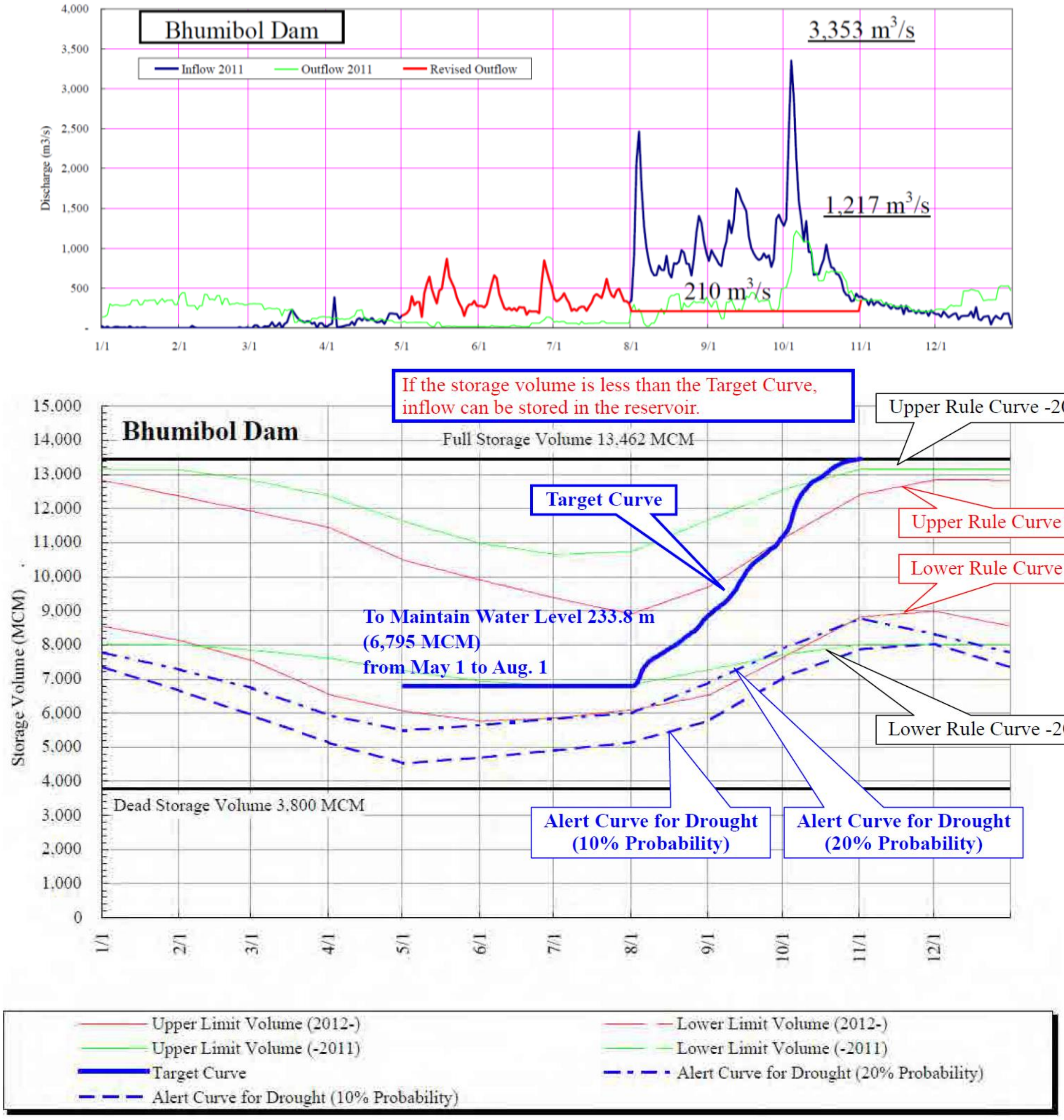
To construct Diversion Channel, 6m depth excavation and 2.8m height embanking are required. In the detail design, studies regarding impacts of excavation and embanking to the neighboring houses, factories, temples and various structures will be required. Especially in Central and South part where soil condition is very soft.

5.2 Recommendation to RID regarding other projects proposed in JICA Master Plan

5.2.1 Efficient operation of existing dams

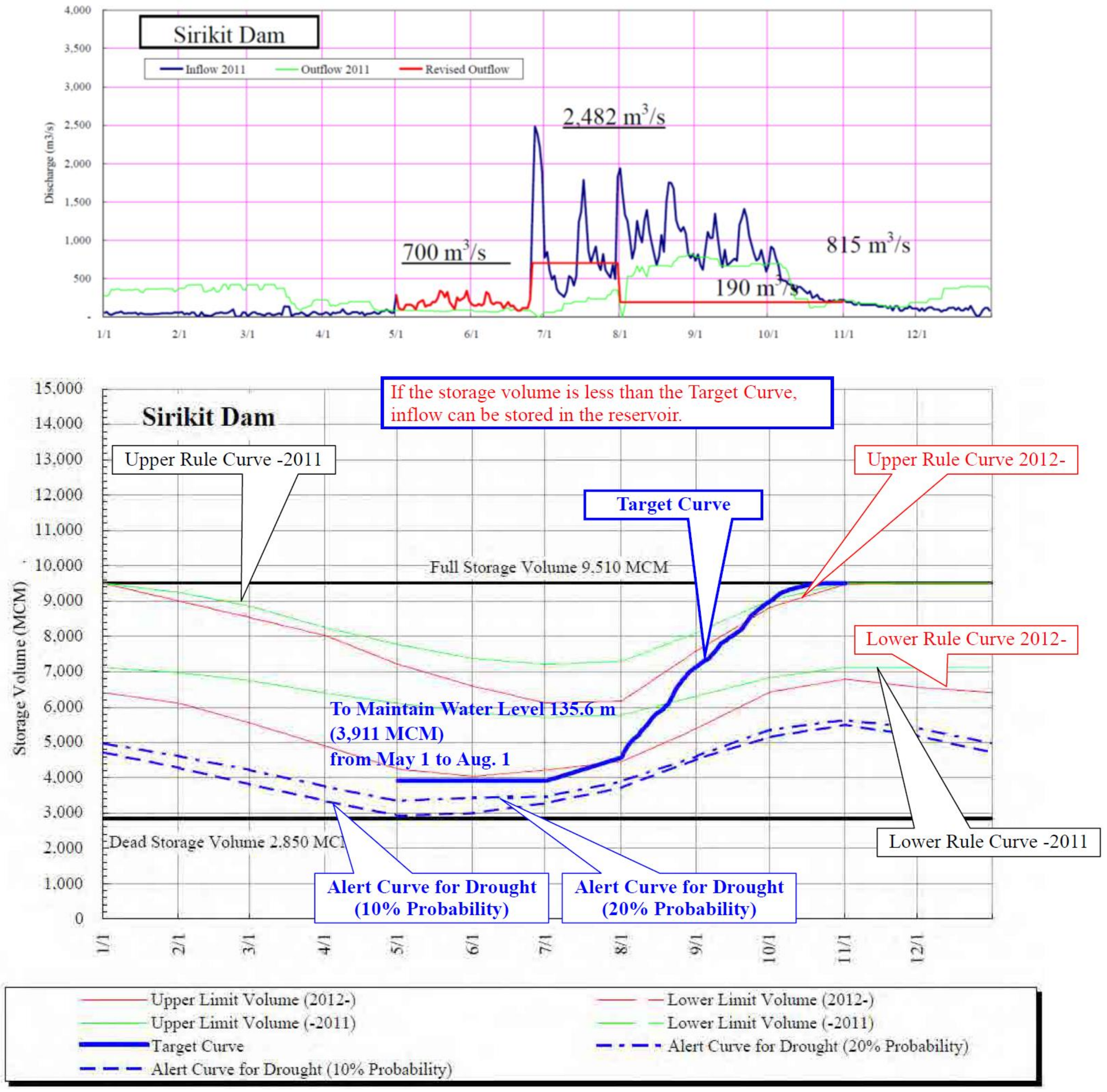
(1) Contents proposed in JICA Master Plan

The operation rules during flooding period at the Bhumibol and Sirikit Dam have been proposed in JICA Master Plan as follows. From May to July, reservoir storage volume should be kept same level in order to store the flood water releasing same amount of discharge as the inflow amount. From August to October, the maximum outflow discharge should be 210m^3/s from Bhumibol Dam and 190m^3/s from Sirikit Dam so as not to increase discharge at the downstream of the dams.



Source : Final report of "Project on a Comprehensive Flood Management Plan for the Chao Phraya River Basin Sept.2013"

Figure 5.2.1 Effective operation of Bhumibol Dam proposed by JICA Master Plan



Source : Final report of "Project on a Comprehensive Flood Management Plan for the Chao Phraya River Basin Sept.2013"

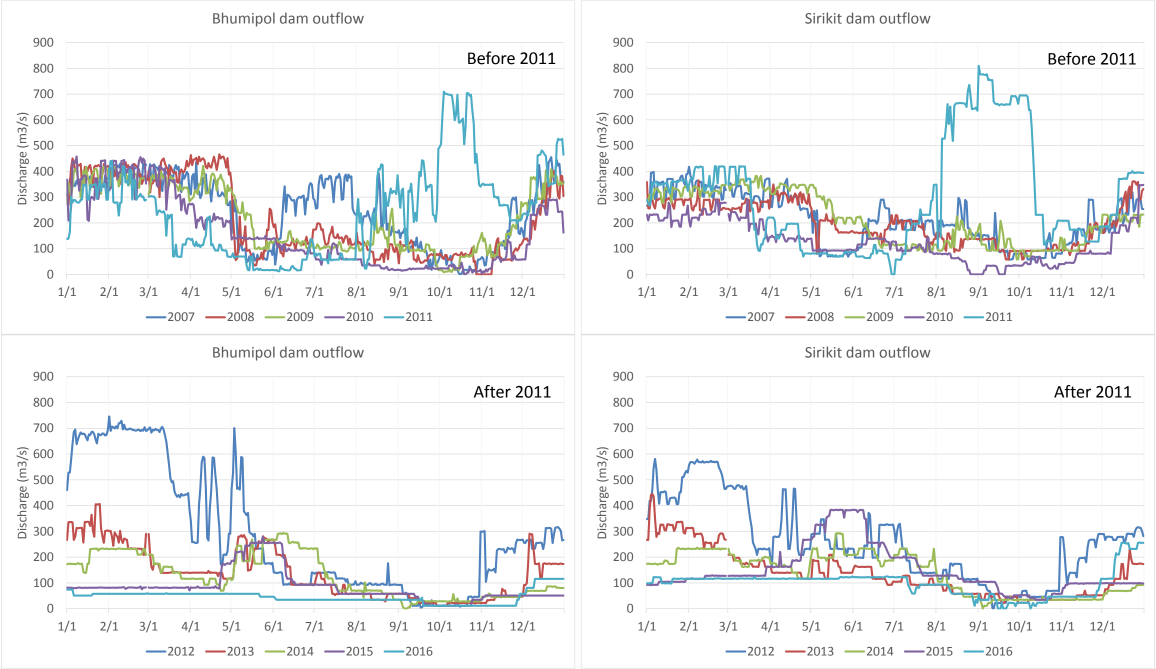
Figure 5.2.2 Effective operation of Sirikit Dam proposed by JICA Master Plan

(2) Correspondence situation of RID

On the other hand, Actual operation of Bhumibol Dam and Sirikit Dam after the 2011 Flood was as follows.

9) Dam operation rule during flooding period

RID has guideline stipulating dam operation for the water utilization during non-flooding period. But there is no rule about the flood control operation. Outflow discharge from dam during flooding period is decided once a week based on the result of meeting discussion held with related organizations. And constant discharge is released from dam during a week. Actual discharge from dams shown in figure 5.2.3 indicates that such operation has been conducted after the 2011 flood. In this figures, actual outflow discharge from dams before 2011 is shown in the upper row and after 2012 is shown in the lower row. The figure in lower row indicates that after 2012 constant discharge was released from dams during a week.

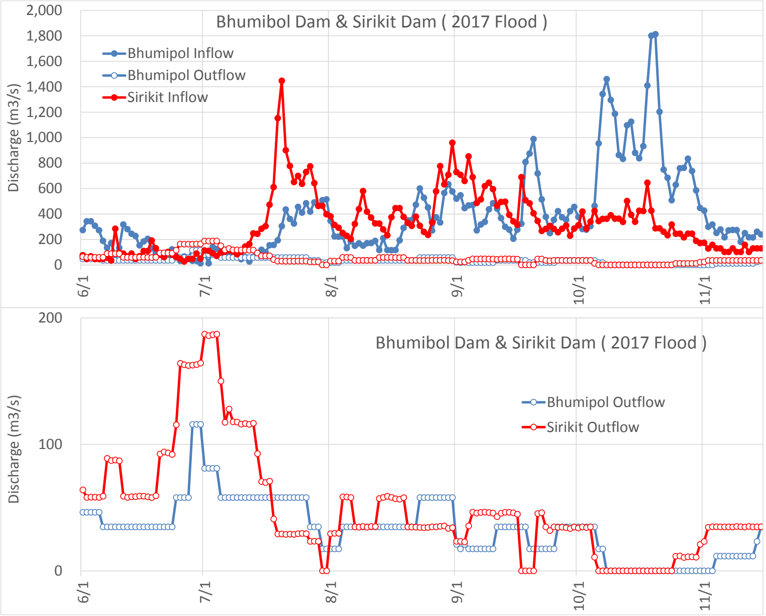


Source : JICA Study Team

Figure 5.2.3 Actual outflow discharge from Bhumibol Dam and Sirikit Dam (from 2007 to 2016)

10)Outflow discharge from dam during flooding period

Outflow discharge from dam is decided considering forecast rainfall by Thailand Meteorological Department (TMD), observed water level in the downstream of dams and discharge from residual basin that is estimated based on the forecast rainfall. Critical Water Level has been set up in each water level observatory. Therefore the relation between actual water level during flooding period and this Critical Water Level can be referred to decide outflow discharge from dams. During flooding period in 2017, outflow discharge had been kept zero during 15 days from Bhumibol Dam and Sirikit Dam (refer to figure 5.2.4).

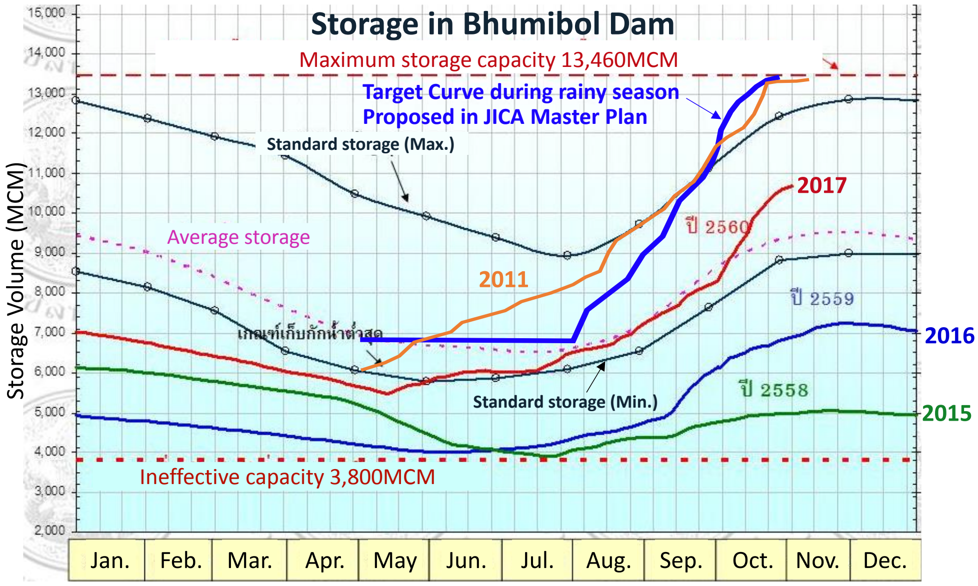


Source : JICA Study Team

Figure 5.2.4 Actual inflow and outflow discharge of Bhumibol and Sirikit Dam during 2017 flood

(3) Challenge and Recommendation

The relation between actual water storage in Bhumibol Dam and Target Curve during rainy season that has been proposed in JICA Master Plan is shown in following figure. In recent years, sufficient vacant volume for storing flood water was prepared in rainy season as shown in following figure. However, as described later, large scale flood has not occurred after 2012. So there has been no performance about efficient dam operation against large scale flood.



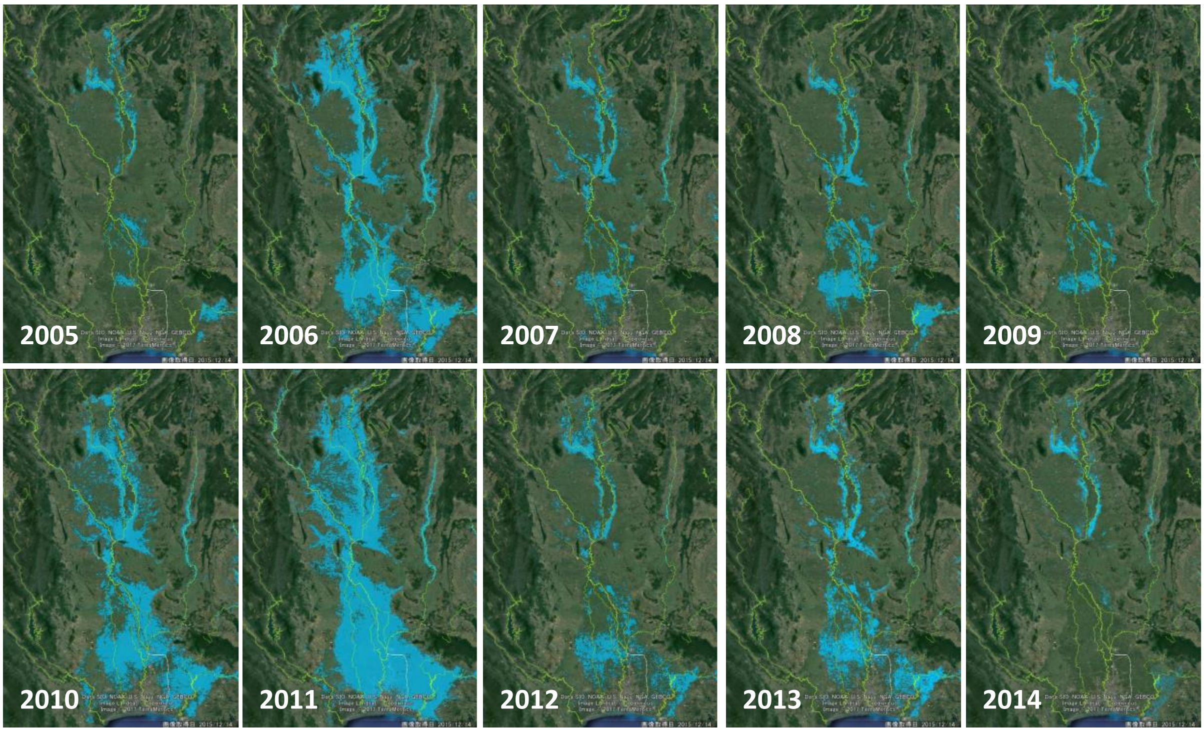
Source : RID website (JICA Study Team added)

Figure 5.2.5 Bhumibol Dam Target Curve during rainy season proposed in JICA Master Plan

In order to operate dam storage efficiently aiming flood control against large scale flood, it is necessary to implement runoff calculation using forecast rainfall, calculation of flood control by dam and inundation calculation in real time. Therefore, it is considered necessary to develop system for deciding outflow discharge from dam, for example to improve existing flood forecast system, and to train for the response in case of flood using such a system.

(4) Reference : Situation of flood occurrence in the Chao Phraya River after 2011

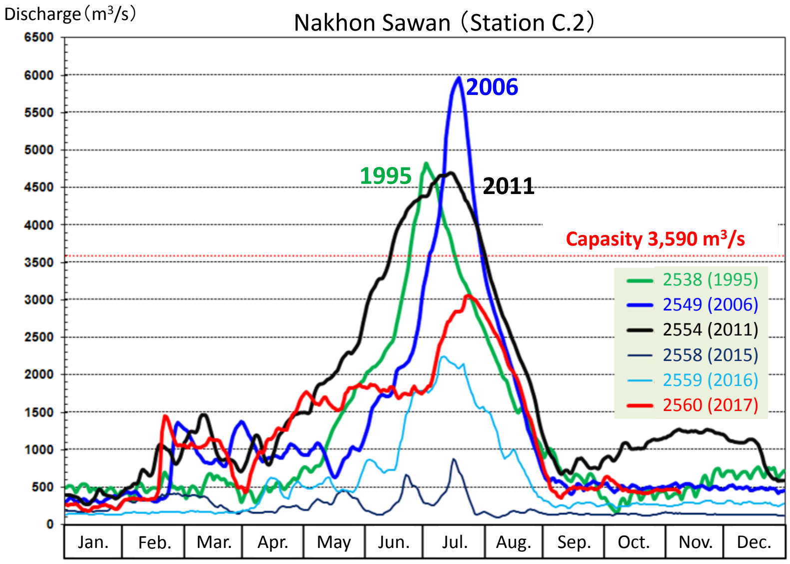
Large scale flood had not occurred in the Chao Phraya River during 2012 to 2017. Inundation by satellite images from Geo-Informatics and Space Technology Development Agency (GISTDA) between years 2005 to 2014 are shown in figure 5.2.6, indicating no large scale floods occurred.



Source : GISTDA website

Figure 5.2.6 Inundation Areas by satellite images between years 2005 to 2014

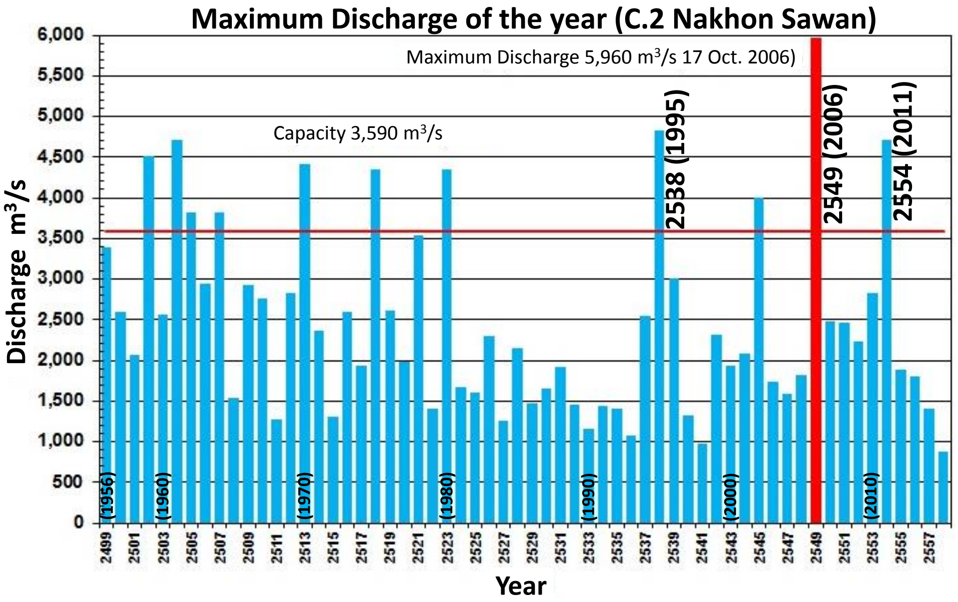
Figure 5.2.7 indicates daily average discharge at Nakhon Sawan (Station C.2). It can be seen that from 2015 to 2017 the discharge at Nakhon Sawan did not exceed 3,590m^3/s which is the flow capacity of this point. Incidentally, large scale floods exceeding flow capacity of this point had occurred in 1995, 2006 and 2011.



Source : RID website

Figure 5.2.7 Actual discharge at Nakhon Sawan (Station C.2) in the years of major flood

Figure 5.2.8 indicates the annual maximum discharge at Nakhon Sawan (Station C.2) from 1956 to 2015. It can be seen that the maximum discharge exceeding 3,590m^3/s which is the flow capacity of this point did not occur from 2012 to 2015.



Source : RID website

Figure 5.2.8 Annual maximum discharge of Nakhon Sawan (Station C.2)

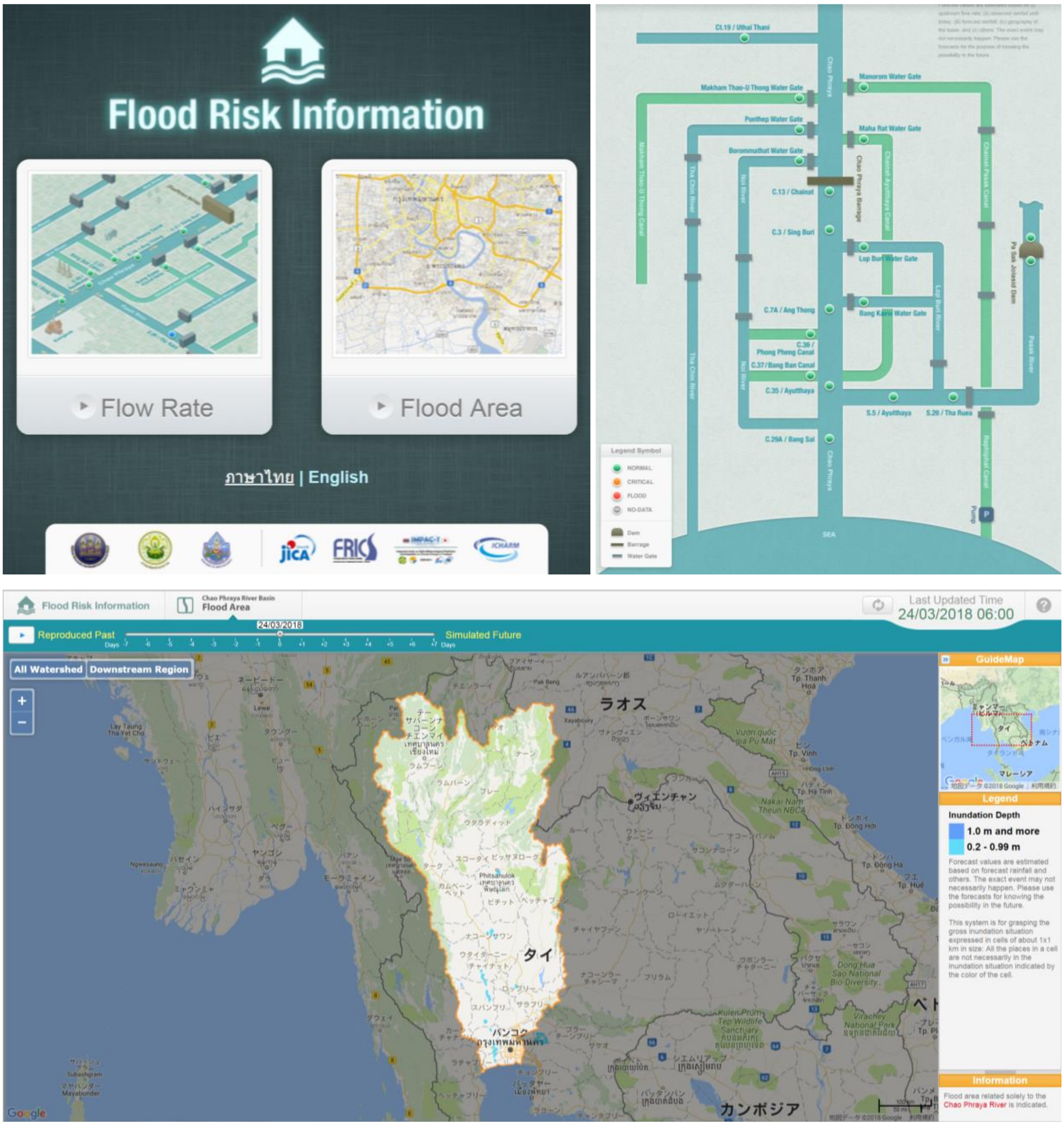
5.2.2 Flood forecast

(1) Contents proposed in JICA Master Plan

Flood forecast system has been developed by RID in 2013 supported by JICA in accordance with the “Project on Comprehensive Flood Management Plan for the Chao Phraya River Basin”. The water level and discharge can be forecasted by the system one week ahead at the major points in the Chao Phraya River and its tributaries, based on the following processing.

- Input the observed rainfall of the past one week, to forecast rainfall for one week ahead.
- Set the inundation area estimated using satellite images, and the observed discharges at some stations in the Chao Phraya River and its tributaries as boundary condition.
- Implement the run-off and inundation calculation.

Forecast rainfall input to this system is the published data by Japan Meteorological Agency (JMA). This data is the simulation result of the meteorological model covering the entire earth including the outputs on the points set at interval of 50 km in both North-South and East-West direction. The number of output points is 720 in the East-West direction and 361 in the North-South direction. Run-off and inundation calculation result is updated once a day and published on the website “Flood Risk Information”



Forecast values are estimated based on forecast rainfall and others. The exact event may not necessarily happen. Please use the forecasts for knowing the possibility in the future.

This system is for grasping the gross inundation situation expressed in cells of about 1x1 km in size. All the places in a cell are not necessarily in the inundation situation indicated by the color of the cell.

Flood area related solely to the Chao Phraya River is indicated.

Source : Flood Risk Information web site

Figure 5.2.9 Flood forecast system in RID (Flood Risk Information)

(2) Correspondence situation of RID

Flood forecast system of RID is published online on the website "Flood Risk Information" which can be publicly accessed and used, especially during a flood season. When there is a possibility of a sever flood, separate warning letters will be sent to the concerned bodies to alert against flooding. The system has been checked for its accuracy using another analysis software.

(3) Recommendation and Further Studies

Interview and discussion had been made with Dr. Thanet Somboon, the concerned officer of RID in charge of flood forecasting. Details of the discussion are summarized in Table 5.2.1 together with the corresponding recommendation from the JICA Study Team.

Table 5.2.1 Discussions and recommendations on the RID's flood forecast system
(Summarized discussions on the RID's flood forecast system and the corresponding recommendations)

Items requiring improvement	Recommendation
<The input forecast rainfall to the system> Currently, there is an inconvenience regarding the input of the forecast rainfall. RID is looking forward to improve this system. The forecast rainfall is input automatically, and the input rainfall is a daily data up to seven days ahead with the average rainfall of 50 km square range. It is more desirable for RID to use the forecast rainfall that RID is able to acquire hourly, averaged in size smaller than 50 km square range.	It is necessary to study for improvement of the rainfall input system of the run-off and inundation calculation model. Under existing condition, forecast maximum and minimum rainfalls are input to the system and the system displays calculation results of water level, discharge and inundation area with range from maximum to minimum. Therefore, the study for using forecast rainfall provided by Thailand Meteorological Department (TMD) in this system is necessary. Moreover, it is necessary to compare forecast rainfall provided by TMD and actual rainfall corresponding to this forecast rainfall and analyze the difference between forecast and actual rainfall.
<Update frequency of flood forecast> Under existing condition, forecast calculation result is updated once a day because daily forecast rainfall is used. However, during flooding period, forecast rainfall or observed water level and discharge are updated once in several hours, it is desirable to shorten the update interval of the calculation results.	During increasing of the discharge in the river for example after the water level at Nakhon Sawan (Station C.2) exceeds "Caution Water Level", it is desirable to raise forecast update frequency. It is necessary to study regarding improvement of the forecast system to raise update frequency, and securing and training human resources for the calculation processing.
<Improve forecast Accuracy> Current system has been indicating forecast water level, discharge and inundation area up to seven days ahead with a range between maximum and minimum value or area. It would be beneficial to make the difference between maximum and minimum forecast value (to reduce the range of forecast error).	There is a possibility to reduce forecast error by using forecast rainfall provided by TMD. Therefore, it is desirable to study adopting forecast rainfall by TMD.
<Saving flood forecast results> Under existing condition, it is not possible to save past forecast results in the computer server. Therefore, RID wants to improve system to be able to save past forecast results.	Large scale data storage medium is necessary to save daily forecast results. Therefore, it is necessary to explore for the calculated data compression method, preparing data storage medium and improving system to be able to save the past forecast results.
<Maintenance and management of the system> RID has some challenges such as staffs in RID can't cope with the trouble on the flood forecast system nor improve the system. Therefore, RID wants to be supported to educate staffs in RID so that they can cope with these problems.	It is conceivable to revise system utilization guideline to more detail or to receive coaching from the Japanese engineers engaged in developing this system.

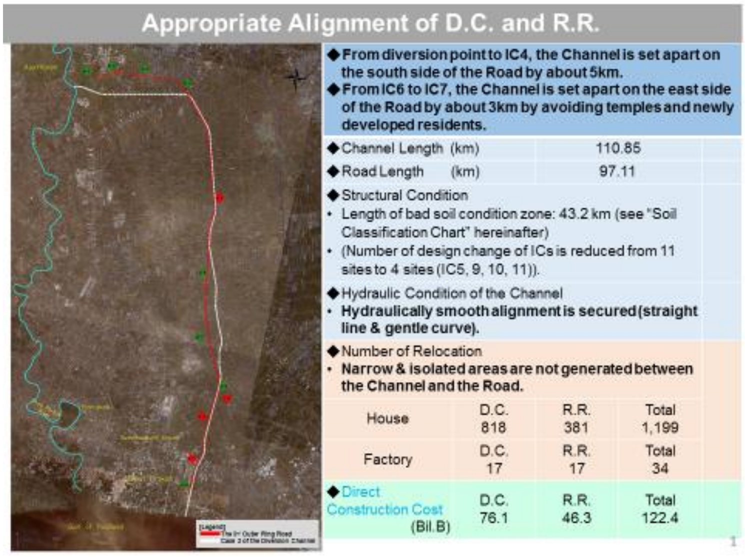
5.3 Correspondences

5.3.1 Correspondence to RID

Questionnaire prepared by JICA and JICA Study Team regarding the RID's 9 projects in the Chao Phraya River basin based on the meeting on November 15 and 16, 2017, was sent to RID. The reply from RID was given to JICA on January 26, 2018. Proposal document by JICA regarding a planning of the 9 flood control projects in the Chao Phraya River basin was then submitted to RID. Detailed documents are attached in Appendix.

5.3.2 Correspondence to NWRC

The project cost of the Outer Ring Road Diversion Channel is needed for RID to determine the priority order of the implementation of flood control projects. The relevant documents by JICA Study Team were submitted to RID, and information was informed to NWRC as well. Submitted documents are shown in the Figure 5.3.1.



Appropriate Alignment of D.C. and R.R.

- **From diversion point to IC4, the Channel is set apart on the south side of the Road by about 5km.**
- **From IC6 to IC7, the Channel is set apart on the east side of the Road by about 3km by avoiding temples and newly developed residents.**

Channel Length (km)	110.85
Road Length (km)	97.11

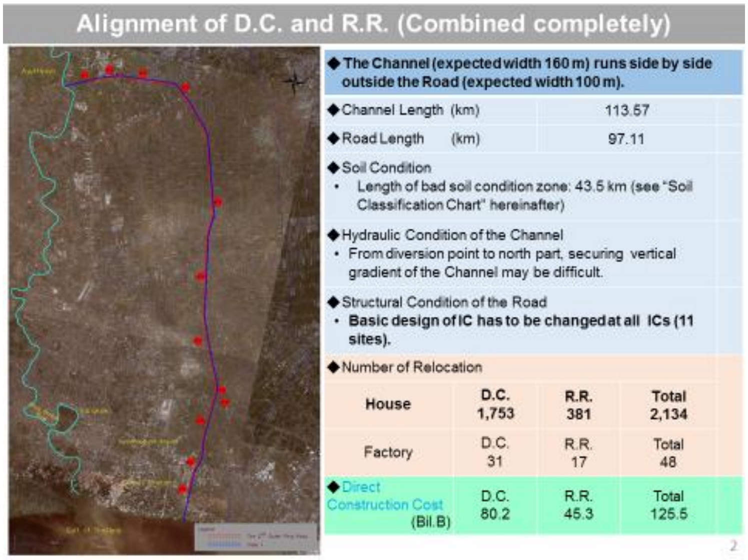
Structural Condition
- Length of bad soil condition zone: 43.2 km (see "Soil Classification Chart" hereinafter)
- (Number of design change of ICs is reduced from 11 sites to 4 sites (IC5, 9, 10, 11)).

Hydraulic Condition of the Channel
- **Hydraulically smooth alignment is secured (straight line & gentle curve).**

Number of Relocation
- **Narrow & isolated areas are not generated between the Channel and the Road.**

House	D.C. 818	R.R. 381	Total 1,199
Factory	D.C. 17	R.R. 17	Total 34
Direct Construction Cost (Bil.B)	D.C. 76.1	R.R. 46.3	Total 122.4

1



Alignment of D.C. and R.R. (Combined completely)

- **The Channel (expected width 160 m) runs side by side outside the Road (expected width 100 m).**

Channel Length (km)	113.57
Road Length (km)	97.11

Soil Condition
- Length of bad soil condition zone: 43.5 km (see "Soil Classification Chart" hereinafter)

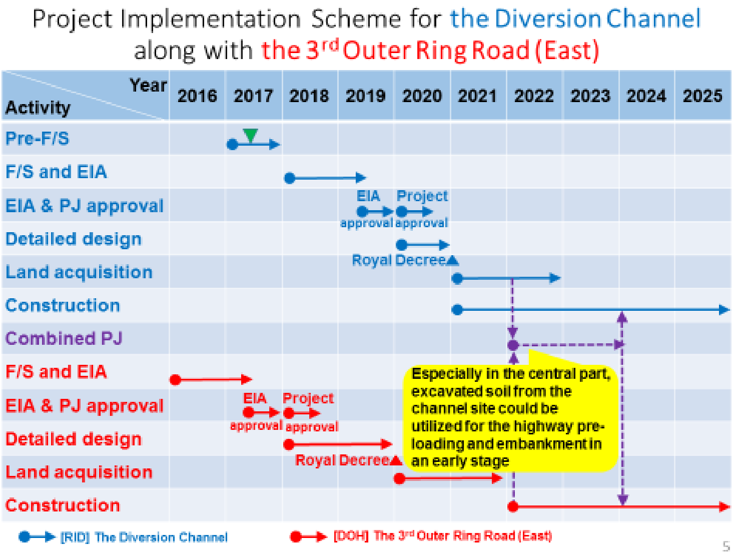
Hydraulic Condition of the Channel
- From diversion point to north part, securing vertical gradient of the Channel may be difficult.

Structural Condition of the Road
- **Basic design of IC has to be changed at all ICs (11 sites).**

Number of Relocation

House	**D.C. 1,753**	**R.R. 381**	**Total 2,134**
Factory	D.C. 31	R.R. 17	Total 48
Direct Construction Cost (Bil.B)	D.C. 80.2	R.R. 45.3	Total 125.5

2



Source : Flood Risk Information web site

Figure 5.3.1 Submitted documents to RID regarding project cost and project schedule

5.4 Recommendation to DOH regarding construction cost reduction

5.4.1 Outline of the DOH Plan

When it comes to the construction stage of the combined project, although the merits in construction is considerable such as possibility to make use of residual soil, cost burden for DOH has to be accommodated according with the figure estimated in the past FS. This is an important topic in the future discussion between RID and DOH. A FS for The Outer Ring Road (East section) has been conducted by DOH in 2011 while the Outer Ring Road (East section) was assumed as an individual project and demand a construction cost of 29,573 Million THB (based on price in 2008). Following the estimation method used in the FS, an updated estimated cost, with cost for essential soil stabilization included and additional cost caused by project combination, is regarded as a part of DOH's burden. Therefore, several case studies were conducted for DOH to reduce the cost burden as follows.

5.4.2 A proposal of road structure change to reduce construction cost

Some contents of previous Basic Plan of the Outer Ring Road are improved to reduce the construction cost. In the previous discussion, Case 2 is selected as the most appropriate alignment for the Diversion Channel, thus following methods to reduce construction cost can be applied to road sections where the Outer Ring Road (East section) runs along the inner side (west side) of the Diversion Channel, namely section 1, 2 and 3:

- To share the road embankment in the inner side of the Diversion Channel as a dike (namely section1 and section 3). This can reduce the construction cost of the bank
- To lower the road level in the area where it is protected with the Diversion Channel

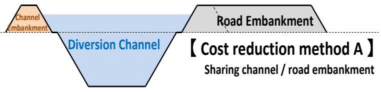
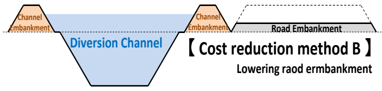
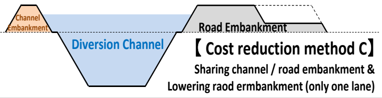
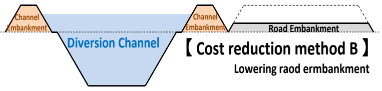
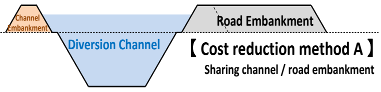
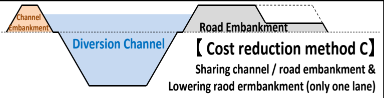
The road level is lowered to be "ground level +1.5m" while it was designed as "ground level + 2.5~3.0m" in the FS of Outer Ring Road. Specifically, three possible types to reduce construction cost in planning and construction, are proposed to DOH as shown below.

Type-A: share the whole road embankment as dike in combined sections (section 1 and 3)

Type-B: lower road level in all 3 sections

Type-C: keep the road level of the lane near to the Diversion Channel as a dike in section 1 and 3, and lower the road level in Section 2

Table 5.4.1 Three possible types to reduce construction cost of the Outer Ring Road

	Type - A	Type - B	Type - C
Section-1 30.0km			
Section-2 29.5km	Nothing		
Section-3 1.8km			
	●Futher EIA is necessary in Method A ●Reduced cost is all distributed to road project	●No need for futher EIA ●All reduced cost will be reflected in road project ●Preferable for DOH	●Futher EIA is necessary in Method C ●Reduced cost is all distributed to road project

Source : JICA Study Team

Source : JICA Study Team

Figure 5.4.1 Alignments of the Diversion Channel and the Outer Ring Road

DOH replied as follows,

- Multiple-utilization (sharing) of the Road is not preferable since the management becomes complicated.
- It is possible to discuss road level lowering further.

※Above are confirmed in the meeting with DOH on October 2, 2017. (See appendix)

Therefore, JICA Study Team is considering Type-B as an option to reduce the construction cost.

5.4.3 Estimated reduction of construction cost

(1) Construction cost as an individual project

An estimated reduction of construction cost is calculated from the view of DOH based on the method of Type-B structure. It is rational to regard the estimated cost in FS as a base line since the project was assumed to be an individual project by DOH. However, following modifications are necessary because cost estimation in FS was made based on the price in 2008 and the structural modification in our proposal.

- estimation is revised using price in 2017
- road structure of south part is changed from embankment to viaduct

The comparison of Case a, Case b and Case c is shown in Table 5.4.2. As a result, a cost of 51,033M THB is updated for the individual project (Case c) as the base line.

Table 5.4.2 Construction cost as an individual project

Items	a. FS Original	b. FS Original	c. FS Original (Elevate road in southern part)
Point of Estimation	Original of DOH	Revise only Unit Price	Change to elevated Structure
Unit Price	as of 2008	as of 2017	as of 2017
Elevating Road in Southern Part	Not Elevate	Not Elevate	Elevate
Direct Construction Cost（Mil.THB）	26,072	34,518	45,162
Indirect Construction Cost（Mil.THB）	3,389	4,487	5,871
Construction Cost（Mil.THB）	29,573	39,005	51,033

Indirect Construction Cost = Direct Construction Cost×Factor-F（ratio of Indirect Cost 0.13)

Source : JICA Study Team

(2) Construction cost as Combined Project

In this study, the construction cost of combined project is estimated to be 54,950M THB which is shown as a basic case (namely Case d) in Table 5.4.3. In this case, all additional cost caused by project combination is regarded as DOH's burden which is estimated to be 4,198M THB in Table 5.4.4.

However, if it is assumed that all additional cost caused by the project combination is ought to be RID's burden, though it has not yet been discussed by RID and DOH, the cost for DOH will be 4,198M THB less than Case d, and estimated at 50,752M THB as (Case e). On the other hand, lowering road level (Type-B) can bring a cost reduction of 4,403 M THB and make the total cost estimated at 50,546M THB (Case f), even with the additional cost as DOH's burden. Furthermore, if we both count the additional cost is regarded as RID's burden and lower the road level, the cost is estimated at 46,348M THB as Case g, which is 8,602M THB less than the individual project plan (Case c).

Table 5.4.3 Cost Estimation as Combined Project

Items	Basic Design	DOHの負担軽減の検討		
	d. Combined Construction	e. Combined Construction (Review increased cost allocation)	f. Combined Construction (Lower road embankment)	g. Combined Construction (Lower road embankment) (Review increased cost allocation)
Measures to reduce project cost of the Road (Cost reduction measure for DOH)	Nothing. Road cost increament by combining with channel is allocated to DOH	Road cost increment by combining with channel is allocated to RID	Reduce road construction cost lowering road embankment	Conduct measures assumed in case e. and f.
Unit Price	as of 2017	as of 2017	as of 2017	as of 2017
Elevating Road in Southern Part	Elevate	Elevate	Elevate	Elevate
Direct Construction Cost（Mil.THB）	48,628	44,913	44,731	41,016
Indirect Construction Cost（Mil.THB）	6,322	5,839	5,815	5,332
Construction Cost（Mil.THB）	54,950	50,752	50,546	46,348
Reduction Cost from case c. (Mil.THB)	-3,917	281	487	4,685
Reduction Cost from case d. (Mil.THB)	-	4,198	4,403	8,602

Indirect Construction Cost = Direct Construction Cost×Factor-F（ratio of Indirect Cost 0.13)

Source : JICA Study Team

Table 5.4.4 Cost Reduction for DOH derived from project combination

（This is the additional cost caused by project combination, which used to be regarded as DOH’s burden and will be regarded as RID’s burden）

Items		Amount (Mil.THB）
Crossing points with Diversion Channel (Length of bridge is 820m)		635
Extended length of bridge crossing with Diversion Channel (2 places)		86
Overpass at the crossing with existing road (Width 6m, 28 places)		918
Modifying structure of interchange (4 places)		1,734
Service road in the area of Diversion Channel (use excavated soil)		111
Service road at the side of Diversion Channel (purchased sand)	Material coost (sand), Transportation cost)	88
	Mixing and compaction cost	143
Subtotal (Direct Cost)		3,715
Indirect Cost		483
Total (increased cost caused by combining with Diversion Channel)		4,198

Indirect Construction Cost = Direct Construction Cost×Factor-F（ratio of Indirect Cost 0.13)

Source : JICA Study Team

5.4.4 Conclusion

Cost burden of the Outer Ring Road (East section) for DOH has been revised. As indicated by Case g, a cost reduction of approximately 4,685M THB (15.9B JPY) for DOH can be achieved by integrating the projects, which is 9% less compared with construction as an individual separate project in the original FS plan.

Table 5.4.5 Construction cost of the 3rd Outer Ring Road (Case study for cost reduction)

Items			Unit	Case a.			Case b.			Case c.			Case d.				Case f.			
				FS (Original)			FS (2017 unit price)			FS Review (Elevated in Southern Part)			Combined Construction				Combined Construction			
				Quantity	Unit price (THB)	Amount (1000THB)	Quantity	Unit price (THB)	Amount (1000THB)	Quantity	Unit price (THB)	Amount (1000THB)	Quantity	Unit price (THB)	Amount (1000THB)	Remark	Quantity	Unit price (THB)	Amount (1000THB)	Remark
Highway (Embankment)	RC Pavement	t=25cm	m2	1,478,016	885	1,308,044	1,478,016	930	1,374,555	1,277,208	930	1,187,803	1,277,208	930	1,187,803		1,277,208	930	1,187,803	
	Sand Bed	t=10cm	m2	1,478,016	61	90,159	1,478,016	137	202,488	1,277,208	137	174,977	1,277,208	137	174,977		1,277,208	137	174,977	
	AC Road Shoulder	t=5cm	m2	805,600	230	185,288	805,600	195	157,092	729,700	195	142,292	729,700	195	142,292		729,700	195	142,292	
	Base Course	t=20cm (Macadam)	m3	214,289	700	150,002	214,289	314	67,205	220,969	314	69,300	220,969	314	69,300	Excluding Transportation	220,969	314	69,300	Excluding Transportation
	Subbase course	t=15cm (Laterite)	m3	445,256	550	244,891	445,256	119	52,914	375,951	119	44,678	97,861	119	11,630	Excluding Transportation	97,861	119	11,630	Excluding Transportation
	Subgrade / Embankment	t=245cm (High Quality Soil)	m3	12,857,800	340	4,371,652	12,857,800	102	1,307,638	11,064,834	102	1,125,294	2,899,954	102	294,925	Excluding Transportation	2,899,954	102	294,925	Excluding Transportation
	Mixing Material	Sand for Mixing	m3										4,467,362	135	603,094		1,761,520	135	237,805	
		Cement (7%)	ton										42,599	2,700	115,018		42,599	2,700	115,018	
		Lime (5%)	ton										120,553	2,700	325,494		106,321	2,700	287,067	
	Mixing Cost (include Transportation Cost)	Plant (8 places)	m3										13,402,087	292	3,916,090		5,284,559	292	1,544,148	
	Embanking Material Transportation Cost (Sand Pit→IC-4)	t=20cm (Macadam)	m3			Including Transportation	214,289	361	77,420	220,969	361	79,834	220,969	361	79,834		220,969	361	79,834	
		t=15cm (Laterite)	m3				445,256	369	164,267	375,951	369	138,699	97,861	369	36,104		97,861	369	36,104	
		t=245cm (High Quality Soil)	m3				12,857,800	369	4,743,602	11,064,834	369	4,082,127	2,899,954	369	1,069,874		2,899,954	369	1,069,874	
		Sand for Mixing	m3										4,467,362	241	1,076,009		1,761,520	241	424,280	
	Embanking Materil Transportation Cost (IC-4→Construction Site)	t=20cm (Macadam)	m3			Including Transportation	214,289	263	56,384	220,969	204	45,122	220,969	156	34,426		220,969	156	34,426	
		t=15cm (Laterite)	m3				445,256	284	126,367	375,951	264	99,200	97,861	52	5,126		97,861	52	5,126	
		t=245cm (High Quality Soil)	m3				12,857,800	193	2,476,059	11,064,834	183	2,021,754	2,899,954	52	151,911		2,899,954	52	151,911	
		Sand for Mixing	m3										4,467,362	162	725,930		1,761,520	162	286,241	
	Soil Cement Slab	t=60cm	m3	854,640	230	196,567	854,640	278	237,846											
	Pile STA65+0-97+112	22cm x 22cm	m	4,273,200	550	2,350,260	4,273,200	666	2,843,815											
	Soil Cement Slab	t=60cm								723,644	278	201,390								
	Pile STA56+579-83+790	22cm x 22cm								3,618,221	666	2,407,926								
	PVD STA 56+579-83+790	1.0m*1.0m	m										22,641	96,558	2,186,170		22,641	96,558	2,186,170	
	PVD STA 35+500-56+579	2.0m*2.0m	m							21,079	19,950	420,526	20,069	19,950	400,377		20,069	19,950	400,377	
	Sodding Work / Fence etc.					330,637			476,117			410,803			410,803				410,803	
Highway (Elevated)	STA 83+700～97+112	6 lanes	m							13,412	1,001,743	13,435,379	13,412	1,001,743	13,435,379		13,412	1,001,743	13,435,379	
	Service Road	2 lane	m	41,820	16,750	700,485	67,314	5,800	390,421	67,314	5,800	390,421								
	Inside Road Area(Mixed Soil)		m										36,024	3,550	127,885		36,024	3,550	127,885	
	Inside Channel Area(Mixed Soil)		m										31,290	3,550	111,080		31,290	3,550	111,080	
Adjoing Fwacilities etc.	Crossing with Diversion Channel STA21+015	Length of Bridge is 820m	m			0			0			0	820	774,000	634,680	1 place	820	774,000	634,680	1 place
	Bridge	Crossing with existing channel or existing main road				2,308,660			2,978,171			1,882,963			1,882,963	8 places			1,882,963	8 places
	Crossing with existing Road	I Gireder	m	3,200	209,000	668,800	3,200	269,610	862,752	3,200	269,610	862,752	3,200	269,610	862,752	9 places	3,200	269,610	862,752	9 places
	(Additional for Diversion Chanel)	Extended Length is 160m	m										320	269,610	86,275	2 places	320	269,610	86,275	2 places
		Segmental Girder	m	612	400,000	244,800	612	516,000	315,792	612	516,000	315,792	612	516,000	315,792	1 place	612	516,000	315,792	1 place
	Underpass (w＝6m)	Community Road	m	2,684	51,600	138,494	2,684	68,112	182,813	2,258	68,112	153,797	486	68,112	33,102	9 places	42	68,112	2,861	1 place
	Overpass (w＝6m)	Increament by Combining	m										8,370	109,650	917,771	20 places	11,550	109,650	917,771	28 places
	Interchange	11 places		11か所		9,487,000			10,937,796			10,937,796			10,937,796	11 places			10,937,796	11 places
	(Additional for Diversion Channel)	Increament by Combining													1,734,716	4 places			1,734,716	4 places
	Box Calvert	Small irrigation channel	m	6,818	25,000	170,450	6,818	33,000	170,450	6,504	33,000	214,632	6,504	33,000	214,632	105 places	6,504	33,000	214,632	105 places
	Service Area					117,000			154,440			154,440			154,440				154,440	
	Tallgate, Other Facilities					874,100			1,153,812			1,153,812			1,153,812				1,153,812	
	Traffic Control and Pricing System					1,728,000			2,348,760			2,348,760			2,348,760				2,348,760	
	Traffic Sign etc.					224,000			367,360			367,360			367,360				367,360	
	Environmental Development (Soundproof Wall)					183,285			292,504			292,504			292,504				292,504	
Subtotal						26,072,600			34,518,800			45,162,133			48,628,886				44,731,568	
Factor F (13% without VAT)			%	13.0		3,389,438	13		4,487,444	13		5,871,077	13		6,321,755		13		5,815,104	
Construction Cost						29,573,000			39,006,244			51,033,210			54,950,642				50,546,672	

Source : JICA Study Team